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IMPREGNATION OF CONCRETE PIPE

Southwest Research Institute

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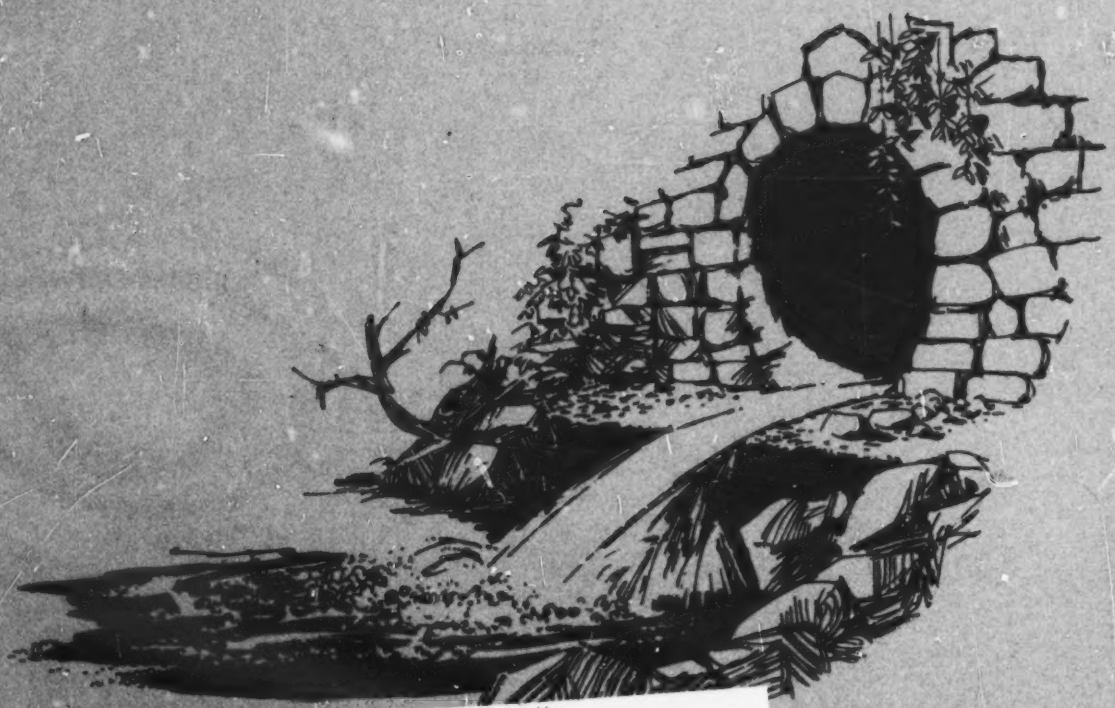
Impregnation of Concrete Pipe



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178

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IMPREGNATION OF CONCRETE PIPE

for the

WATER QUALITY OFFICE
ENVIRONMENTAL PROTECTION AGENCY

Details of illustrations in
this document may be better
studied on microfiche.

by

Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78228

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ABSTRACT

This program was undertaken to investigate methods to increase the corrosion resistance, increase the strength, and reduce the permeability of concrete used in sewer line applications by impregnating the concrete pipe with relatively low cost resins such as asphalt, coal tars, linseed oil, sulfur, urea-formaldehyde, and others.

Methods to accomplish this end were achieved and the materials, techniques of application, test results and economics are presented in this report. A large number of candidate impregnation materials were obtained and carefully screened both in the laboratory and in limited field tests. Test specimens were cut from commercial grades of concrete pipe and physical property tests were made on the treated specimens both before and after they were subjected to degrading environments created to simulate, but at an accelerated rate, the environment that concrete may be subjected to in sewer applications. Specimens impregnated with sulfur or 5.0% hydrofluoric acid had scaling rates of 0.0005 to 0.00017 respectively as opposed to 0.005 in./day for the concrete control when subjected to a three day exposure in 10% sulfuric acid. This indicates 10 to 30 times greater corrosion resistance than untreated concrete pipe. Six other materials, including vinyl-vinylidene chloride, vinyl acetate-acrylic, nitrile rubber latex, nitrile-phenolic rubber, an emulsified reclaimed rubber, and a rubber base adhesive, although failing to impregnate the concrete, formed surface coatings having exceptional resistance to the 10% sulfuric acid.

Sections of commercial concrete sewer pipe were given applications of these eight different treatments and placed in severe corrosive sewer environments in sites provided by the City of Harlingen, Texas, the City of San Antonio, Texas, and a site on Southwest Research Institute grounds over the winter of 1970-71. Preliminary results from these tests indicate that these eight different treatments are functioning effectively and are thus worthy of further long term evaluation.

This report was submitted in fulfillment of Program No. 11024 EQE, Contract No. 14-12-835, under the sponsorship of the Water Quality Office, Environmental Protection Agency.

Key Words: Concrete Pipe, Impregnation, Hydrogen Sulfide Attack, Acid Attack, Sulfate Attack, Coatings, Chemical Resistance of Concrete.

CONTENTS

Section		Page
I	Conclusions	1
II	Recommendations	3
III	Introduction	5
IV	Background	7
V	Literature Search	13
VI	Initial Laboratory Screening of Materials	15
VII	Optimization of Materials and Procedures	33
VIII	Preliminary Field Tests	41
IX	Significance of Laboratory and Field Findings	45
X	Economics	49
XI	Acknowledgements	55
XII	References	57
XIII	Appendices	59

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LIST OF FIGURES

		Page
1.	Cross Section of Concrete Sewer Pipe Under Typical Corrosion Conditions.	8
2.	Corrosion of the Floor of a Concrete Lift Station.	10
3.	Preferential Acid Attack on Limestone Aggregate by Industrial Wastes.	11
4.	Water Absorption as a Function of Time Under Varying Conditions of Vacuum and Pressure for 18 in. Diameter Concrete Pipe.	16
5.	Preferential Attack of Limestone Aggregate in Laboratory.	19
6.	Scaling of Concrete Pipe as a Function of Sulfuric Acid Concentration.	20
7.	Corrosion Caused by 1, 5, and 10% Sulfuric Acid Solutions After Three-Days' Exposure.	22
8.	Extended Exposure of Concrete to 10% Sulfuric Acid.	23
9.	Treatment Plant Corrosion Caused by Citrus and Tomato Acid.	27
10.	Flexural Strength as a Function of Pipe Age for Sulfur Impregnated Concrete.	36
11.	Flexural Strength of Impregnated Concrete as a Function of Sulfur Temperature.	37
12.	Staining of Concrete by Sodium Sulfide Solution.	44
13.	Surface Attack of Sulfuric Acid.	46
14.	Selling Price as a Function of Pipe Diameter for Various Types of Sewer Pipe.	50

TABLES

No.		Page
1.	Properties and Corrosion Resistance of Promising Concrete Treatments	31
2.	Performance of Selected Double-Treated Specimens	35
3.	Absorption and Strength of Sulfur Impregnated Concrete Pipe at 30 Psig Pressure	39
4.	Relative Economics of Treating Concrete Pipe	52

SECTION I

CONCLUSIONS

1. Improvements in the corrosion resistance, impermeability and strength of concrete pipe can be achieved by impregnation. The importance of these improvements from an applications standpoint rank in the order given.

2. Although a number of materials improved the corrosion resistance of cured concrete pipe, (Appendix A) the most promising impregnation materials found were a 5% solution by weight of hydrofluoric acid, sulfur and a modified sulfur formulation.

   The concrete pipe control specimen when subjected to sulfuric acid for 3 days suffered a scaling rate (wall loss) of 0.005 in./day. The flexural strength of the concrete was found to be 1160 psi.

   The concrete specimen impregnated with a 5% solution of hydrofluoric acid when subjected to the same test as above suffered scaling of 0.00017 in./day. The flexural strength was 1050 psi.

   A concrete specimen impregnated with a modified sulfur formulation when subjected to the same test as above, suffered scaling of 0.0005 in./day. The flexural strength was 2800 psi. In addition, the water absorption of the concrete was reduced from 5% to 0% when impregnated with sulfur.

3. Three days submergence in 10% sulfuric acid is an extremely severe test for concrete. A solution of 10% sulfuric acid is the most corrosive concentration as shown below:

Sulfuric Acid Concentration (% by wt.)	Scaling (in./day)
0.1	o.00025
0.5	0.0008
1.0	0.0015
5.0	0.004
10.0	0.0054
30.0	0.0015
50.0	0.0007
98.0	0.0

4. Although maximum sulfuric acid concentrations of approximately 5% have been determined in certain sewer lines, the maximum scaling rate uncovered in the literature has been 0.5 in./yr or 0.0014 in./day. This is the same scaling rate obtained in the laboratory using a 1% sulfuric acid. Thus, it would appear that 1% sulfuric acid could simulate the most severe environment expected in the field. This should be examined further.

5. Before reliable predictions can be made on the durability of impregnated concrete pipe, good correlations must be established between laboratory experiments and field performance.

6. Materials which failed to impregnate concrete, but which formed good surface coatings included latexes of vinyl-vinylidene chloride, vinyl acetate-acrylic, nitrile-phenolic, nitrile rubber, a rubber base adhesive, and an emulsified reclaimed rubber product. Predicting durability or service life of concrete treated with these coatings is extremely difficult. Pinholing, abrasion, or mechanical damage will expose the concrete, subjecting it to corrosive attack. The use of these materials should be limited to areas where visual inspection and manual application can or must be performed.

7. Better coatings were obtained by using wetted rather than dry concrete specimens. Dry specimens tended to generate gas bubbles which caused pinholing in the coating. The fact that the walls in such appurtenances as wet wells and diversion boxes are damp, make the water base latexes of vinyl-vinylidene chloride, vinyl acetate-acrylic, nitrile rubber, and emulsified reclaimed rubber particularly attractive for such applications. Materials' costs per square foot of treated area for coatings range between 6 - 8 cents.

8. The cost of impregnating concrete pipe with hydrofluoric acid will vary between 5 and 10 cents per square foot, while impregnation with sulfur will vary between 8 and 15 cents per square foot. Typical costs for epoxy-coal tar or plastic liners vary between 85 cents and one dollar per square foot. Until service life is established for impregnated pipe, a cost effectiveness comparison cannot be made.

9. The possibility that sewer lines can be treated in place, using hydrofluoric acid in a manner similar to that used in the oil industry for acidizing oil and gas wells is of considerable interest and potential.

SECTION II

RECOMMENDATIONS

1. The use of 5% hydrofluoric acid, sulfur and modified sulfur formulations has proven successful in impregnating concrete pipe to improve corrosion resistance as measured in the laboratory. Field testing using these treatments, supported by additional laboratory work should allow for the development of a good correlation between laboratory and field tests. The fact that 1% sulfuric acid has been found to impart the same scaling rate as that of the most severe sewer line cases reported in the literature is encouraging and should be further pursued so that a valuable aid can be developed for laboratory evaluation.

2. Pipe sections impregnated with hydrofluoric acid and sulfur along with a concrete control should be placed in test in domestic sewage lines and in industrial waste lines which have a recorded history of severe concrete corrosion. Preferably this should be accomplished in several cities to insure measurable differences in a minimum of time.

3. A representative sewer line should be selected and a portion should be treated in-place using 5% hydrofluoric acid. The line should be monitored and a comparison made between the treated and non-treated sections to determine the success of in-place treatment.

4. A facility such as a wet well, diversion box, treatment tank, or junction box that is partially corroded should be coated with one or more of the water base latexes. A four walled structure would be ideal since vinyl- vinylidene chloride, nitrile rubber, vinyl acetate-acrylic, and reclaimed rubber could be applied to each wall and be compared directly with one another in the same installation under the identical environmental conditions.

5. The fact that Ocrated (a treating process using silicon tetrafluoride gas) concrete pipe is attacked by dilute sulfuric acid and yet reportedly performs satisfactorily in sewer service indicates that a re-evaluation of some of the resins and treatments investigated on this program may be in order. The effect of any natural bactericidal effect or that of added bactericides could conceivably control the bacteria population responsible for the generation of sulfuric acid and thereby allow some of these materials to provide adequate

corrosion resistance in a sewer line application, even though they would not pass the 10% sulfuric acid corrosion test in the laboratory.

6. The best treatment methods as determined in the field tests should be given a complete process design and economic analysis, so that prospective users would have this material available to them as an aid in making the decision with regard to installation of such facilities.

SECTION III

INTRODUCTION

Concrete is a low cost, high strength material that is resistant to water damage at normal temperatures. Because of this, concrete is used extensively in water and sewer systems. Corrosion of concrete in sewers is not a new occurrence, but has been in evidence for years. The severity of the problem has greatly increased in recent years because of the rapid expansion of the population, industrial growth, the use of garbage disposal units, and a reduction in the amount of dilution of the sewage due to tighter joints and to a reduction in the use of combined sewers. In sewer systems with a history of corrosion problems a variety of conditions occur regularly that cause the generation of sulfides which are oxidized to sulfuric acid and this aggressively attacks the concrete.

Concrete is also attacked by sulfates, particularly those contained in the surrounding soil and water. The sulfates react with the tricalcium aluminate and free lime in the cement and cause the concrete to deteriorate. Sulfate attack can also occur where there is no native sulfate, in that sulfate is formed when concrete is attacked by sulfuric acid. Thus, attack attributed to sulfuric acid can actually be a combined attack from both acid and sulfate. Impregnation of concrete pipe used in water and sewer systems offers several potential advantages. The interior passages of the concrete structure would be sealed. The permeability and porosity of the concrete would be reduced. The physical and mechanical properties of the concrete would be improved. Realization of these advantages at a moderate cost would result in a longer service life of installations and improved operational efficiency.

The problem of corrosive attack of concrete in these applications has been the subject of extensive past research. Some of the better known developed control techniques included:

1. The use of forced air ventilation of the vapor spaces in sewer lines.

2. The running of sewers liquid full.

3. The control of sewer pH.

4. The use of corrosion resistant sewer pipe such as clay tile, or plastic pipe.

5. The use of epoxy based coatings.

6. The use of complete or partial plastic liners.

7. The use of sacrificial coatings, (thick wall sections; concrete which contain high concentrations of limestone aggregate; etc.)

The objective of the subject program was to investigate a large number of materials as potential impregnants for concrete sewer pipe to impart corrosion resistance, reduce permeability, and improve strength. Some of the materials investigated failed to permeate the concrete specimens, but rather formed a surface coating.

SECTION IV

BACKGROUND

The quantity of concrete pipe used attests to the success that has been achieved with it over a long period of time. Continuous improvements have been made over the years in its design and manufacture, particularly with respect to the joints and the methods of sealing. ASTM Designations: C 14, the Standard Specification for "Concrete Sewer, Storm Drain, and Culvert Pipe", and C76, "Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe" detail tests for design, strength, absorption, and permeability. These tests form the basis on which much of this type of pipe is purchased.

Corrosion of concrete pipe and other concrete structures used in sewers is not a universal problem, but it is a serious problem in some areas. It results in leakage, infiltration, and overloading of treatment facilities. It also results in premature failure of lines necessitating early replacement. Corrosion of concrete in sewer applications has been the subject of numerous investigations. (1, 2, 3) Conventional sewer corrosion occurs above the liquid level and it does not occur in lines that are run liquid full unless some aggressive compound is being discharged to the sewer, usually from some industrial source.

The consensus of investigators regarding the mechanism of sewer corrosion is that it is directly related to the presence of hydrogen sulfide in the vapor space of the sewer and to a lesser extent to heavy sulfate concentrations in the waters carried in the sewers or in the earth surrounding the sewer. The origin of hydrogen sulfide in sewage is from the action of anaerobic bacteria on organic sulfur compounds, sulfates and other inorganic sulfur compounds. They use sulfur instead of oxygen as a hydrogen acceptor. The quantity of hydrogen sulfide produced and released to the vapor space is considered to be a function of the amounts of hydrogen sulfide producing elements in the sewage, the time of reaction, the temperature (minor up to 15 °C, increasing progressively up to 38°C), the pH (a maximum at a slightly alkaline condition), and the degree of agitation or turbulence experienced by the sewage. The hydrogen sulfide entering the vapor space dissolves in the condensed moisture films on the exposed concrete surfaces and is oxidized to sulfuric acid by aerobic bacteria. One such bacteria, thiobacillus thiooxidans, is capable of producing sulfuric acid in concentrations up to 5%. Figure 1 is a sketch showing the mechanism of typical concrete sewer pipe corrosion.

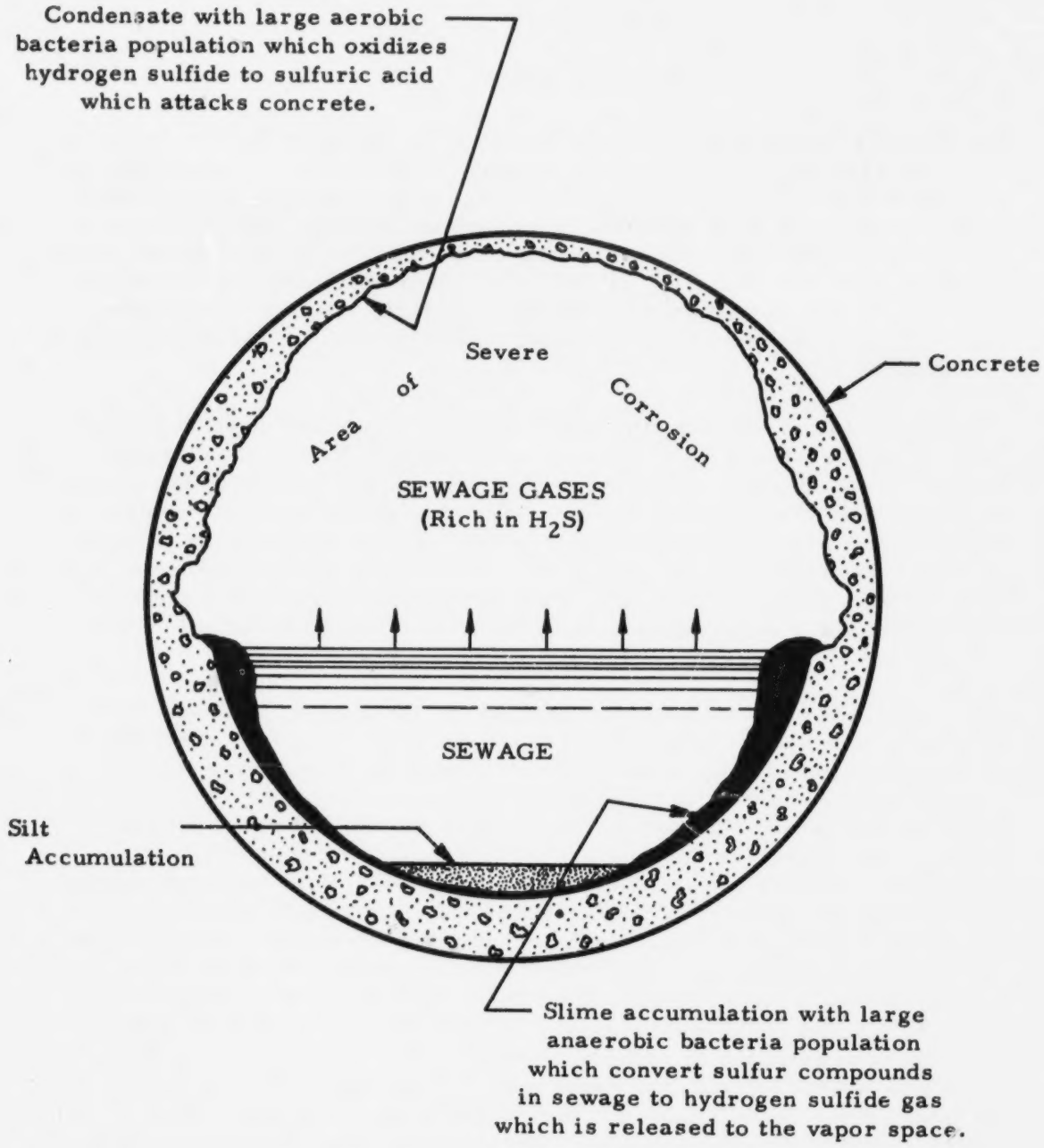
Condensate with large aerobic bacteria population which oxidizes hydrogen sulfide to sulfuric acid which attacks concrete.
Severe
Area of Corrosion
Concrete
SEWAGE GASES
(Rich in H_2S)
SEWAGE
Silt Accumulation
Slime accumulation with large anaerobic bacteria population which convert sulfur compounds in sewage to hydrogen sulfide gas which is released to the vapor space.

Figure 1. Cross Section of Concrete Sewer Pipe Under Typical Corrosion Conditions.

Figure 2 is a closeup photograph of the remains of a floor section of a lift station and is characteristic of the type of deterioration encountered in concrete sewer appurtenances. Note the exposure of the reinforcing steel.

The destructive action of sulfates on concrete is primarily the result of the reaction between the sulfates and the tricalcium aluminate and free lime in the cured concrete product. The crystalline calcium sulfate reaction product is larger in volume than the original constituents and this causes cracking, swelling, and spalling in the concrete which becomes progressively weaker and finally disintegrates.

Numerous investigators (3, 4) have shown by extensive studies of this problem that sulfate attack can be controlled in concrete by keeping the tricalcium aluminate content of the cement used below 5.5% or by curing the pipe with high pressure steam or both. It was also noted by earlier investigators that the less permeable the pipe, the more sulfate resistance it exhibited. The use of sulfate resistant concrete does not impart resistance to sulfuric and other acids.

Other mineral and organic acids often tend to react preferentially with any limestone present in the concrete. An example of this is shown in Figure 3. This type of failure is more often encountered in industrial wastes rather than in domestic sewage. The section of pipe shown in Figure 3 was the top of the line, the bottom half having been completely corroded away. This is the reverse of what is found in sewers handling domestic sewage.

When many users of concrete pipe encounter or anticipate problems with acid or sulfate attack they choose pipe other than that made of concrete. Often the other types of pipe are more costly than concrete pipe. The premium price that these other types of pipe command and their widespread use are related to their superior chemical resistance in problem areas.

The following criteria are thought to be the most significant with respect to the use of concrete pipe:

1. Concrete pipe is subject to both acid and sulfate attack and there are locations where it can be subject to both at the same time. Infiltration into, or seepage from, concrete pipe can develop as a result of the deterioration of the pipe.

Figure 2. Corrosion of the Floor of a Concrete Lift Station

Figure 3. Preferential Acid Attack on Limestone Aggregate by Industrial Wastes

2. Impregnation of concrete pipe can improve its resistance to acid and sulfate attack in that it reduces the permeability of the concrete and thereby denies the deleterious materials access to the interior structure of the concrete and any steel reinforcing. (Corrosion of steel can result in forces created during the formation of iron oxide sufficient to spall concrete).

3. A protective process for concrete sewer pipe should not only impregnate the pipe and reduce its permeability but it should also protect the interior and exterior surfaces from attack.

4. Improvements in strength derived from the protection system are significant and can be used to great advantage, however, strength improvements are not thought to be of the same significance as improvements in corrosion resistance.

5. The cost of the protective systems should be such as to offer a considerable savings over other present day remedied actions such as the use of clay tile, plastic liners, and the various coatings.

SECTION V

LITERATURE SEARCH

This program was initiated with a literature search relating to impregnation and treatment of concrete. In addition to the library facilities of the Institute, the computer abstracting service of the Highway Research Information Service of the National Academy of Sciences was employed. Prior to the literature search, the authors were aware of some very early work (5, 6) relating to the impregnation of concrete and sandstone with sulfur as well as some recent work on impregnation of concrete with polymer materials (7, 8, 9) being conducted at Brookhaven National Laboratory by the Bureau of Reclamation, Atomic Energy Commission and Office of Saline Water. Limited investigations of impregnating concrete sewer pipe with sulfur (10) demonstrated the technical and economic feasibility for improving strength and reducing permeability. One other known protective treatment for concrete sewer pipe was the Dutch Ocrate process (11) wherein silicon tetrafluoride gas was impregnated under pressure into concrete pipe to improve its corrosion resistance.

The literature search failed to uncover any additional treatments or processes for impregnating concrete as relates to controlling corrosion resistance. Several good references were uncovered, however, on coatings or treatments for waterproofing or protecting concrete in general. (12,-14) These documents served as valuable guidelines insofar as materials which showed any promise as simple waterproofing agents were generally considered as potential impregnants.

SECTION VI

INITIAL LABORATORY SCREENING OF MATERIALS

With the valuable literature references, the laboratory phase of the program was initiated.

Impregnation Techniques

In addition to samples obtained from the local concrete pipe manufacturers, samples were also requested from various plants throughout the United States. However, most of these contacts referred us to the local manufacturers and as a result, all of the data generated in this program were obtained from pipe that was manufactured from plants in San Antonio, and Harlingen, Texas. The fact that concrete pipe is manufactured according to rigid ASTM standards should insure that the concrete pipe is a fairly uniform product. This was confirmed by representatives of the American Concrete Pipe Association and from our limited laboratory tests.

The impregnation procedure used throughout this program was as follows:

> Concrete specimens predried at 250°F for 12 hours were completely submerged in the impregnating solution. The vessel containing the specimens and solution was then placed inside a larger pressure vessel. Depending upon the particular solution, a vacuum of between 26 and 28 inches of mercury was then applied, followed immediately by a positive air pressure with the specimens still submerged in the impregnating liquid.

In initial experiments, specimens from 4, 6, 12, and 27 in. diameter pipe were first dried and then submerged in water and subjected to 28 in. of mercury vacuum. The weight gain for all of the specimens subjected to vacuum for 10 minutes varied between 5.5 and 6.5%. When subjected to vacuum for 15 minutes followed by 30 psig for 10 minutes, the weight gain varied between 6 and 7%. No major absorption differences were found among the various diameter pipe. Eighteen in. diameter pipe was selected for test work because of its relatively thick wall.

Sections of 18 in. diameter pipe were submerged and subjected to pressures varying from 10 to 50 psig for timed intervals. The results of these tests are shown in Figure 4. It was found that the bulk of the absorption takes place in the first 10 minutes of submersion and above 10 psi the absorption

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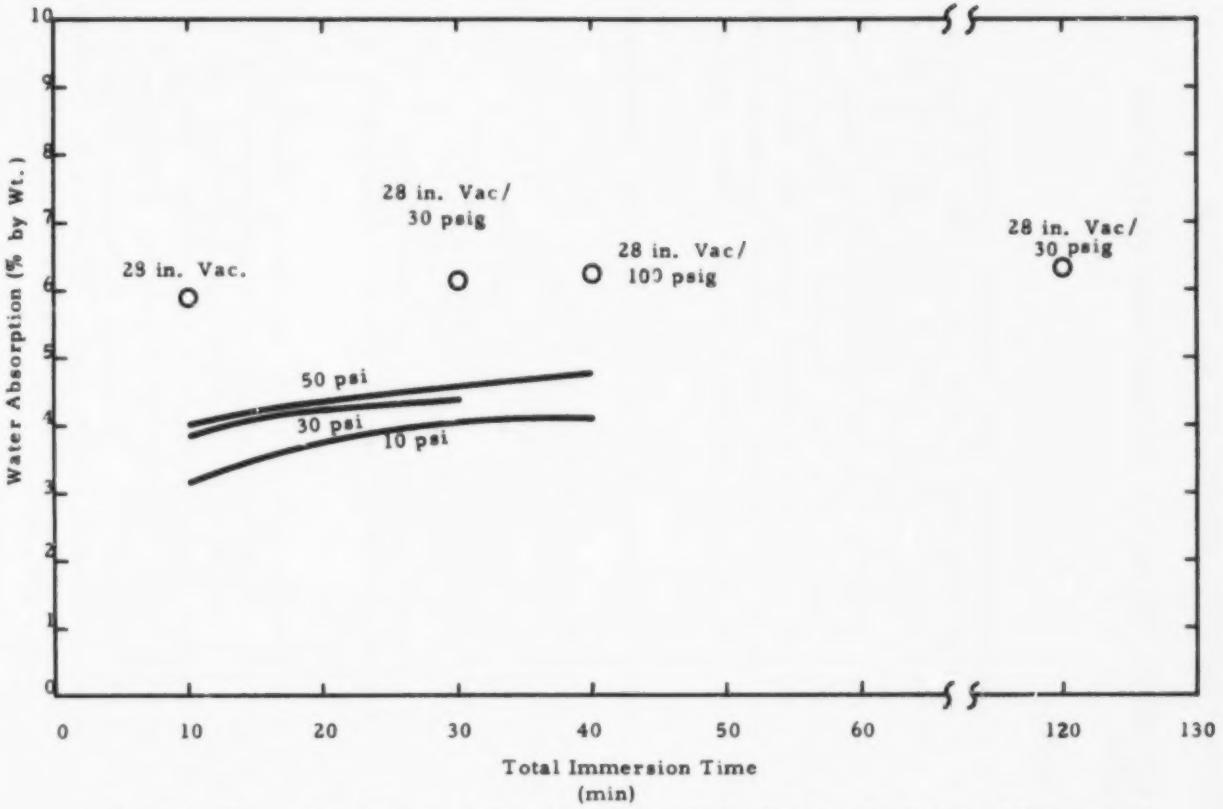


Figure 4. Water Absorption as a Function of Time Under Varying Conditions of Vacuum and Pressure for 18 in. Diameter Concrete Pipe

is relatively independent of pressure. Next, specimens were impregnated under vacuum only and then vacuum followed by pressure. Specimens were submerged under vacuum only for 10 minutes, under vacuum for 15 minutes followed by 30 psig for 15 minutes (total immersion time of 30 minutes), under vacuum for 20 minutes followed by 100 psig for 20 minutes, and under vacuum for 1 hour followed by 30 psig for 1 hour. These data are also shown in Figure 4. The standard procedure adopted for preparing test specimens was to subject the specimens to a 28 in. mercury vacuum for 30 minutes followed by 30 psig pressure for 30 minutes for a total immersion time of one hour, with some allowance being made for some of the more viscous impregnants.

Specimens were submerged in various impregnating solutions in separate containers. Several of these containers were then placed in a large pressure vessel and in this manner, a number of materials could be run at one time.

Mechanical Properties

A common problem in any type of screening program conducted in the laboratory is the selection of appropriate tests that relate to field performance. For strength determinations flexural strength was selected since specimens for this test could easily be prepared by cutting the cured concrete pipe with a diamond bladed saw. Tensile strength may have been a better test, however, preparing suitable specimens from cured concrete pipe was not practical. The standard D-load test wherein concrete pipe is placed horizontally and then subjected to a compressive load along its horizontal axis is used extensively in industry. If ring sections had been used instead of flexural specimens, it would have required large volumes of impregnating materials, large impregnating vessels, and the specimens would have been less convenient to handle. In addition, the resulting data from a D-load test is not easily related to a fundamental stress property which is dependent on specimen dimensions. This was important since the specimen dimensions changed after exposure to the corrosive media.

The flexure specimens were prepared from non-reinforced 6 in. concrete pipe and were approximately 0.5 in. x 1 in. x 5 in. Each specimen was carefully measured with a vernier caliper and broken in flexure. The average flexural strength or modulus of rupture for the untreated pipe was approximately 1160 psi. Specimens with a number of larger pieces of aggregate in the broken cross section tended to be lower than this

(690 psi) while specimens without large aggregate in the broken cross section tended to be higher (1360 psi). As a result, differences in flexural strength were not viewed as significant unless they were orders of magnitude different.

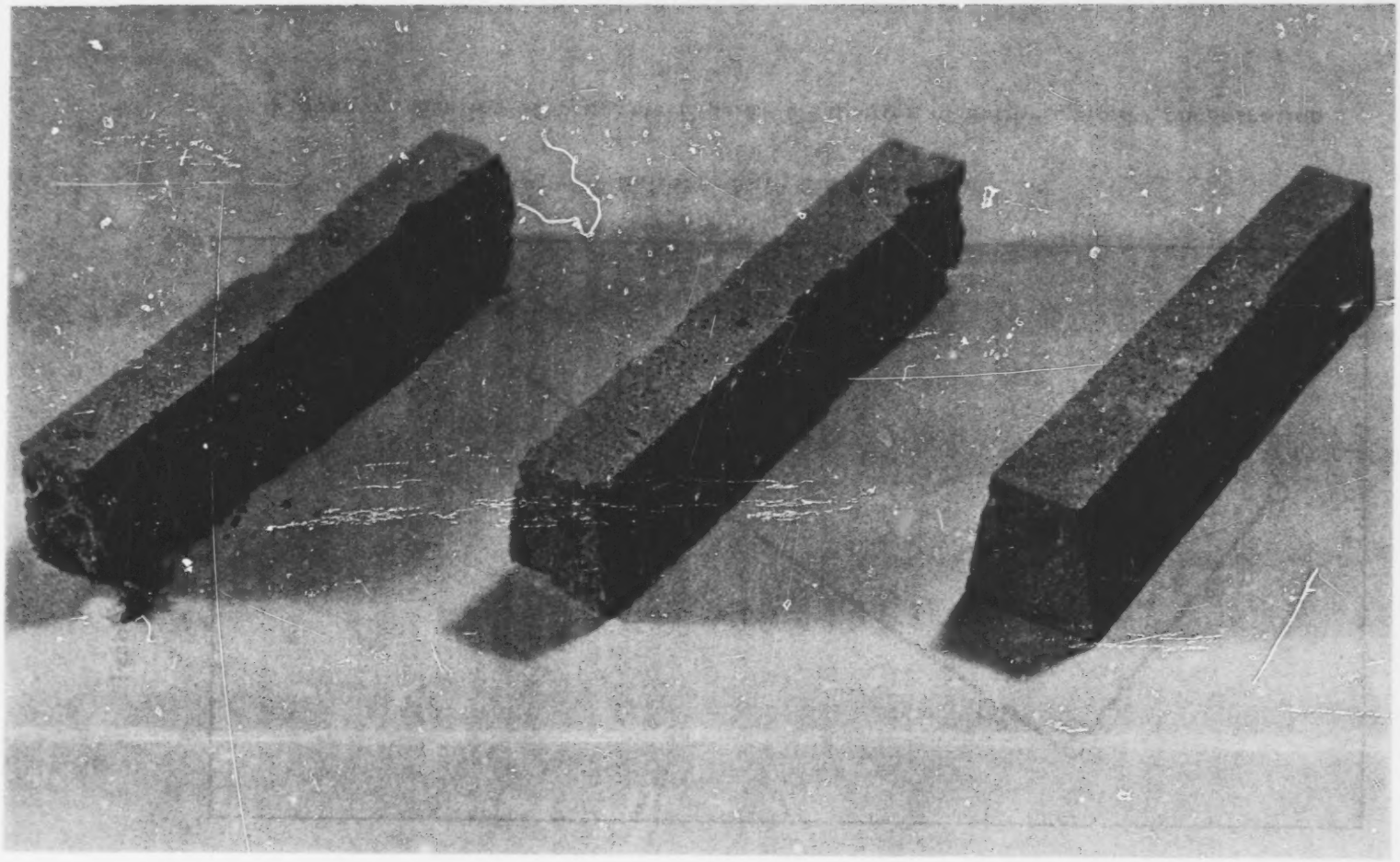
Corrosion Tests

Selection of the corrosive media was based on the fact that sulfuric acid is the most prevalent type of corrosive attack encountered. Preliminary laboratory tests showed that attack by dilute sulfuric acid was immediate, being measurable after several days, whereas sulfate salts took considerably longer. Also, from laboratory experiments it was observed that dilute sulfuric acid attacked the mortar preferentially to the limestone aggregate such that ultimate attack was very similar to prolonged sulfate attack. The normal attack of other acids, including concentrated sulfuric acid, is preferential attack on the limestone aggregate which leaves depressions in specimens as indicated in Figure 5 and almost identical to that shown in Figure 3.

Scaling rate as used throughout this report to determine corrosion rate, is a measure of the erosion of the concrete pipe wall reported as in. /day. Laboratory experiments were conducted wherein dif erent acid concentrations were evaluated for a 3-day exposure period. Figure 6 plots the scaling rate versus sulfuric acid concentrations and shows a maximum rate of approximately 10% concentration of sulfuric acid. Although the 98% sulfuric acid attacked the limestone aggregate, it did not attack the mortar. The 0.5, 1, 10, 30, and 50% solutions preferentially attacked the mortar, whereas the 0.1% sulfuric acid attacked both the limestone aggregate and mortar at about the same rate.

As a final consideration, ASTM "Standard Methods of Testing Clay Pipe" (C 301-68) requires a 48 hour exposure of the clay pipe to a 1N solution of hydrochloric, nitric, sulfuric, or acetic acid. For sulfuric acid this is equivalent to a 5% weight solution. The maximum concentration of acid measured in working sewer lines has been approximately 5%.

For the laboratory tests, the most severe acid attack was desirable so that corrosion would occur in a minimum period of time. Thus 10% sulfuric acid was selected as the preliminary screening corrosive media because it was more severe than the 5% reported in sewers, the scaling rate was easily measurable after 3 days, and there was never any indication that the 10% sulfuric acid was attacking or charring any of the



10% HCl 10% HNO_3 98% H_2SO_4

Figure 5. Preferential Attack of Limestone Aggregate in Laboratory

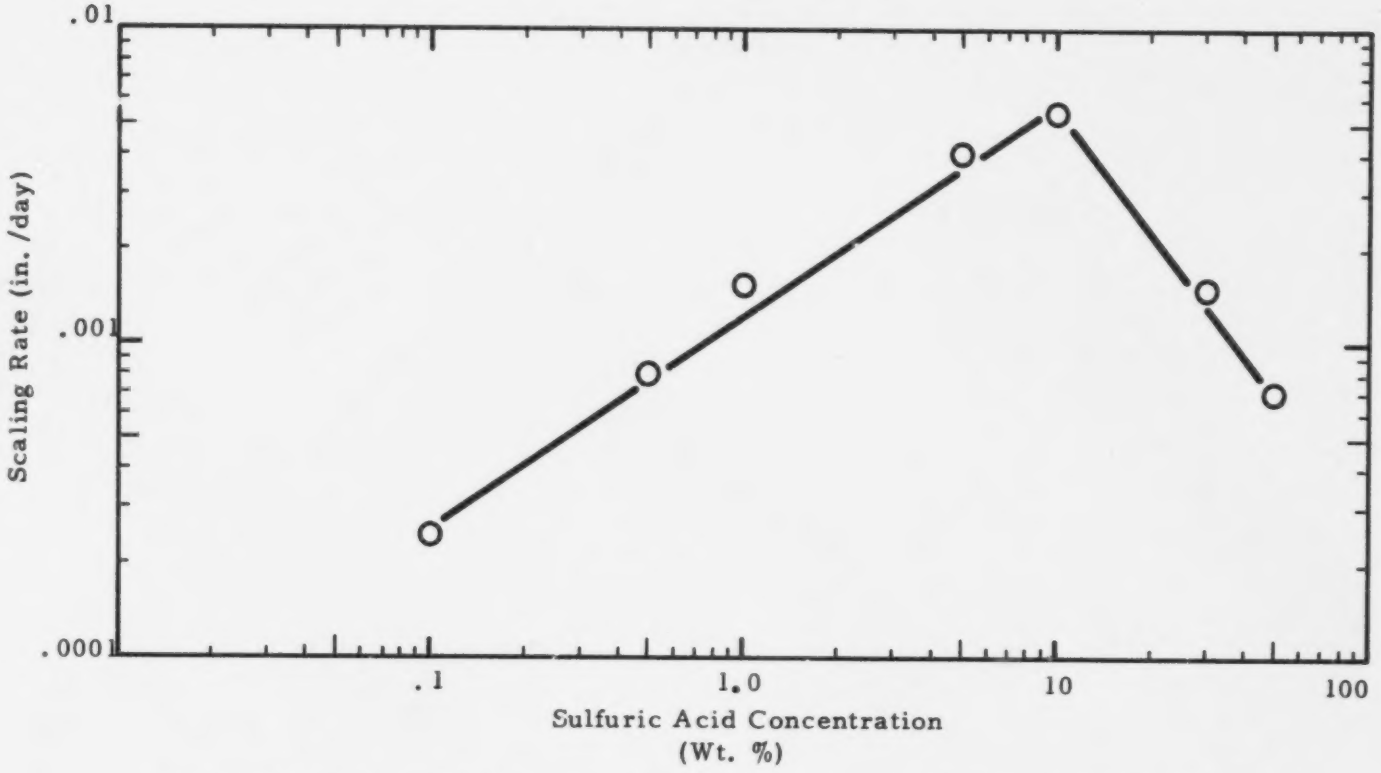


Figure 6. Scaling of Concrete Pipe as a Function of Sulfuric Acid Concentration

treatments. More concentrated solutions of sulfuric acid have been known to char hydrocarbon materials. Typical 3-day attack of 1, 5, and 10% sulfuric acid on concrete is shown in Figure 7.

Figure 8 shows the typical performance of the concrete pipe used throughout this study for an extended period of time in 10% sulfuric acid. Most of the large aggregate protruding is limestone, whereas the mortar is principally silica sand and cement. As already explained, this phenomenon has been recognized and is the principal reason why some pipe manufacturers are considering switching to high limestone aggregate concrete in sewer pipe production.

Types of Protective Systems

Generally speaking, there are three principal ways of protecting cured concrete pipe from corrosive attack. One way that has been of principal interest in this program has been the impregnation or saturation of the voids within the concrete pipe with an inert or noncorrosive material. Preferably this material is a good film-former as well as a good wetting agent for the concrete constituents. While simply blocking the pores or void spaces within the concrete should slow down and limit attack to the surface only, unless the material readily wets the concrete particles and forms an impermeable barrier, corrosion will occur.

A second means of protecting the concrete is to initiate a chemical change in the concrete itself, whereby the soluble and/or more reactive constituents are insolubilized or changed to a less reactive species. Because of the complex nature of concrete itself, as well as the complexities that can occur with the resultant chemical reactions, this particular means of protecting concrete is usually better evaluated by performance studies. This area includes steam curing of concrete, the silicate and fluosilicate treatments, fluoride treatments, carbonating, etc. This approach is potentially as attractive as impregnation, particularly if more than a surface treatment can be obtained. Unfortunately, most of these treatments afford only surface protection, or form gels which provide some protection under very mild acid conditions, but not against typical sewer acid concentrations. These treatments have been used principally as surface hardening, or water proofing applications in the past.

The third means of protecting concrete from attack is by the use of coatings. This area has received by far the most attention in the past. While there are commercial coatings available which are currently used in sewer applications, the most successful are usually relatively thick

Figure 7. Corrosion Caused by 1, 5, and 10% Sulfuric Acid Solutions After Three-Days' Exposure

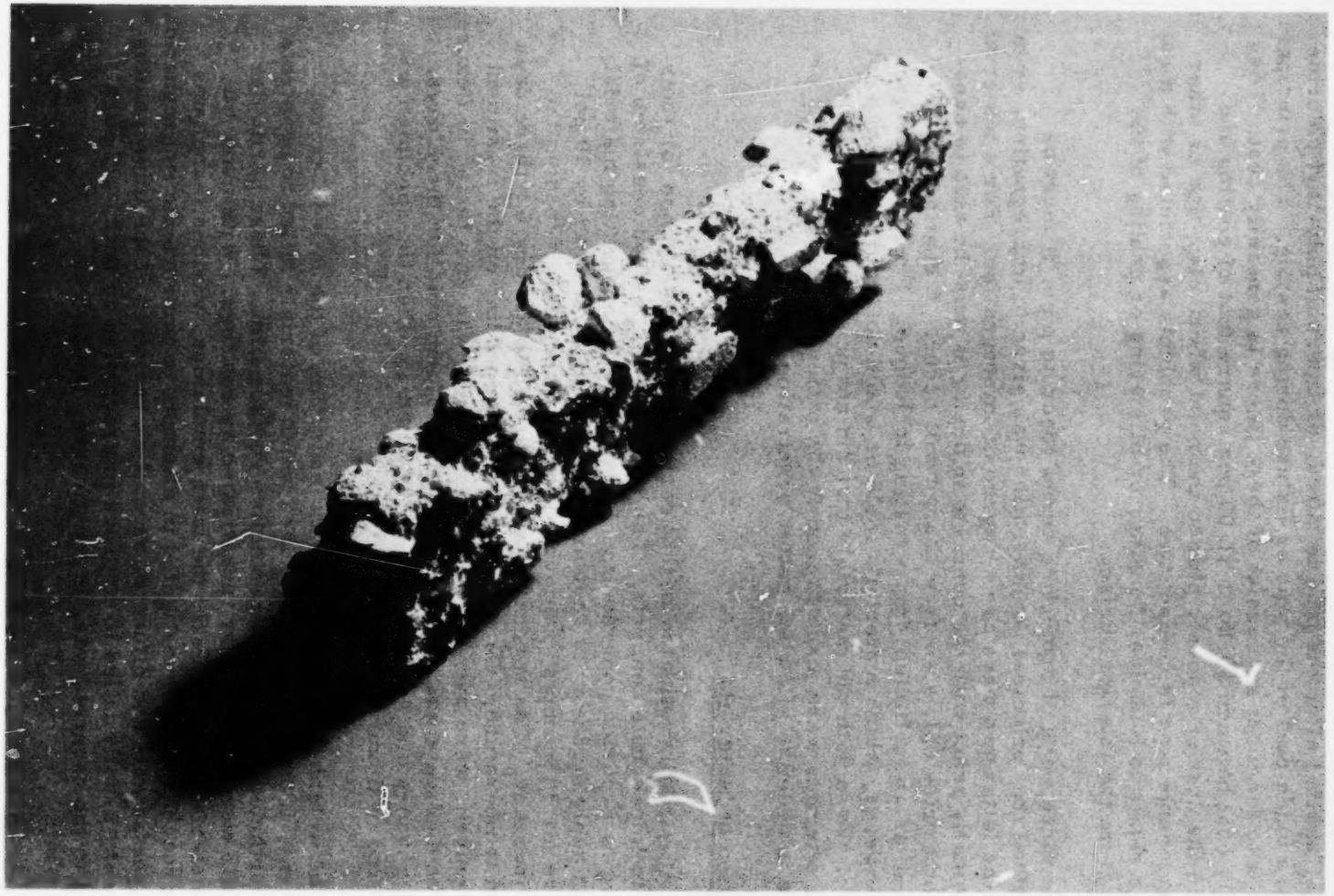


Figure 8. Extended Exposure of Concrete to 10% Sulfuric Acid

coatings, applied after the pipe is cured, or liners of polyvinyl chloride which are made part of the pipe or fixture during casting. The principal drawback to the most successful of these liners is generally cost. They normally cost between $0.80 to $1.00 per square foot of coating and increase the cost of concrete pipe to the point where clay pipe or other more expensive pipe is competitive. The problems associated with most coatings relate to pinholes, bonding, or blistering or peeling of the coating from the interior surface.

Of these three ways of protecting cured concrete pipe, it must be emphasized that principal consideration was given to impregnation, even though the latter two ways are a degree of impregnation. For a material to chemically react with the concrete in depth, it must be able to penetrate, otherwise only a surface change will occur. A coating can be thought of as an inefficient impregnating technique. Predicting beforehand, however, which materials would or would not impregnate was not possible. Even with the materials that did not penetrate, but simply coated, attempts were made to modify the material with surfactants or diluents in order to allow for better penetration.

Evaluation of Materials

Thus materials investigated in this study were first screened for their ability to impregnate concrete. The standard test method consisted of submerging predried concrete specimens in the impregnating material and then applying 28 in. of vacuum for 30 minutes followed by 30 psi pressure for 30 minutes, removing the specimens and recording the weight increase. The specimens were allowed to air dry for three days at room temperature. Certain specimens, depending on the treatment they received, were oven dried. One specimen was then tested in flexure, while the duplicate was submerged in 10% sulfuric acid for three days. The weight loss and scaling were determined and then the specimen was also tested in flexure.

From the weight increase as well as inspection of the failed flexural specimens, it was easily determined which materials failed to penetrate, but nevertheless did offer a protective surface film. These particular materials were then further investigated as coatings. With many of these materials, particularly the latex emulsions, various techniques and approaches were investigated in attempts to improve the impregnation. Use of surfactants and diluents, as well as variation of the impregnating conditions, usually failed to improve impregnation as such, although bonding to the concrete was, in most cases, improved.

Materials which reacted with the concrete were also observed after the impregnation procedure. Usually these materials underwent a surface reaction which was destroyed in the 10% sulfuric acid. The more promising materials, however, penetrated in depth and caused a chemical reaction throughout the concrete.

By comparing the weight loss and scaling rate of the treated specimens against that of the concrete control, several promising materials were singled out and further evaluations were conducted.

A complete list of materials evaluated and their performance is included as Appendix A. A brief description of the performance of the various types of treatments will be discussed, with further elaboration on some of the more promising materials.

During the course of this program approximately 100 different chemicals or materials were evaluated. The general classes of materials can be broken down into water soluble salts or acids, water base latexes, solvent base latexes, liquid resins, and hot melts. One principal problem encountered with all of the materials which coated the surface of the specimen was drainage of the material from sharp edges. This left a relatively thin coating in these areas which the acid rapidly penetrated. A brief review of each class of materials follows.

Water Soluble Salts and Acids

This class of materials included silicates, fluosilicates, fluorides, phosphates, and oxalates. The silicates and fluosilicates required a series of treatments, wherein dilute solutions were followed by more concentrated solutions. These materials did not give adequate protection for the intended application. This is not surprising since others have found that these treatments are usually poor waterproofing agents as well. (15)

Several experiments using varying concentrations of hydrofluosilicic acid were conducted since it was expected that a treatment similar to that of the Ocrate process would be obtained. The resistance to sulfuric acid was poor, whereas Ocrated concrete is reported to give good corrosion resistance in sewer applications. In checking the literature, (16) it was found that sulfuric acid does attack Ocrated concrete, although its success in sewer applications is related to a reported bacterial effect which inhibits the formation of sulfuric acid on the concrete walls. (16, 17)

The only materials from this group which appeared encouraging were a commercial product by the name of SP-4 (Patented Product of Roadways International, Baton Rouge, Louisiana) and a dilute solution of hydrofluoric acid. According to the label, SP-4 also included hydrofluoric acid. The fact that the hydrofluoric acid does impart corrosion resistance is unexpected since it is usually recognized as a corrosive material to concrete. Specimen numbers 1 and 3 in Appendix A give the specific data on these treatments. The treated specimens suffered a weight loss of from 2.3 to 2.7 grams as compared to 9.2 for the concrete control. In addition, a scaling rate of 0 to 0.00017 was obtained as compared to 0.0054 in./day for the control.

Water Base Latexes

This class of materials included copolymers of vinyl chloride and vinylidene chloride, acrylics and vinyl acetate; polyvinyl acetate and copolymers of vinyl acetate and acrylics; copolymers of acrylonitrite and butadiene-styrene; natural rubber emulsions; and reclaimed rubber emulsions. None of these materials impregnated the concrete, but rather gelled or formed a coating on the concrete surface. Gelling was more pronounced on dry concrete specimens. The use of water wetted specimens did not improve penetration. By far the most promising materials of this group were the vinyl chloride-vinylidene chloride copolymers, a vinyl acetate-acrylic copolymer, a nitrile rubber, and a reclaimed rubber emulsion. Even these materials, however, if not applied in sufficient thickness, allowed acid to pass by way of pinholes. If properly applied, these coatings completely protected the concrete from acid attack. The principal applications envisioned for this class of materials are the protection of manholes, junction boxes, wet wells, treatment tanks, and other concrete structures which lend themselves to easy visual inspection, wherein failed sections can easily be detected and repaired. A typical potential application is shown in Figure 9. The bulk of this damage occurred when the pH of the sewage dropped to 2 during one canning season for citrus and tomatoes in Harlingen, Texas.

The fact that these are water emulsions makes them attractive from an application point of view because of essentially no toxic odors or fumes, good adherence to damp concrete walls, as well as easy clean-up of

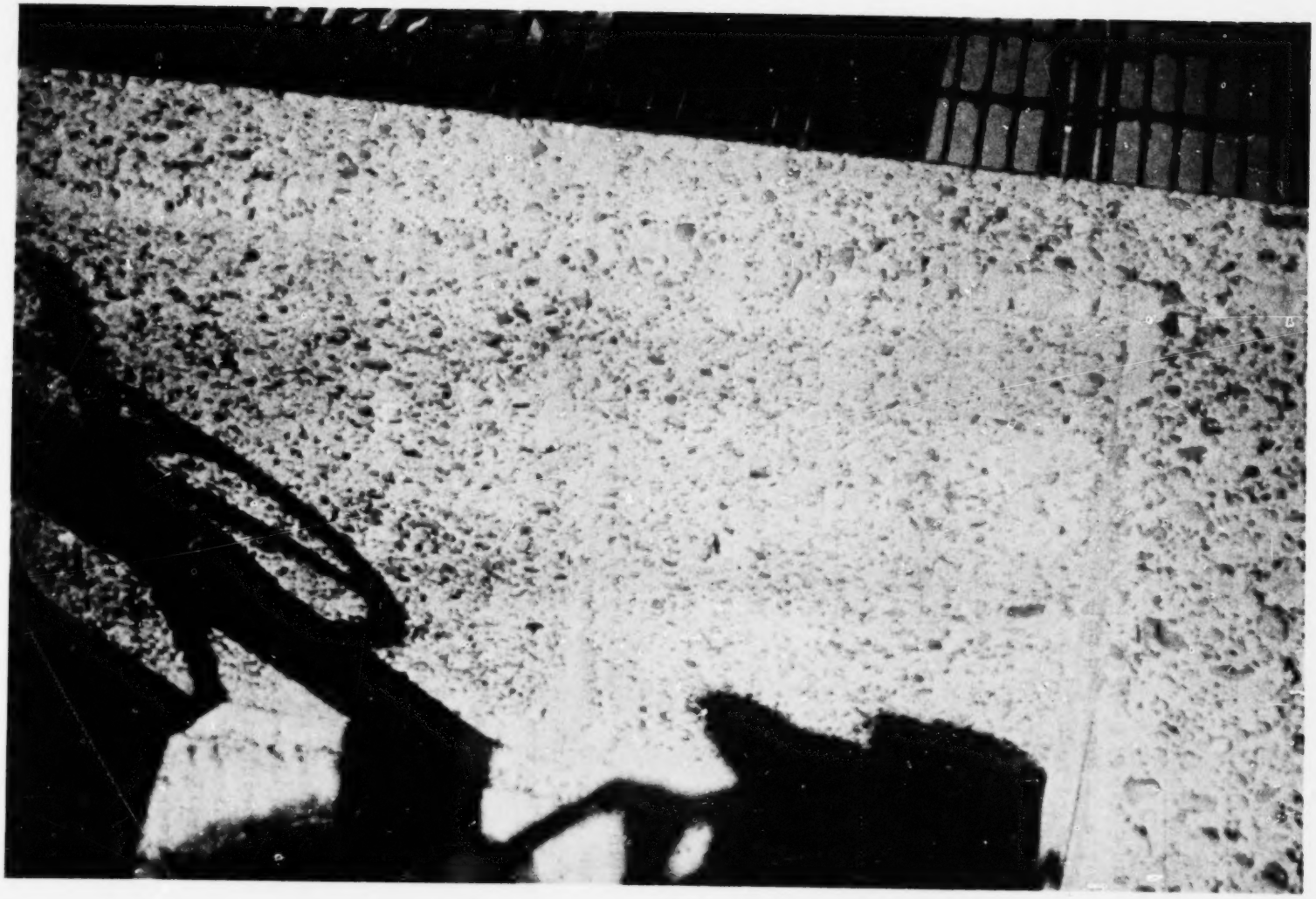


Figure 9. Treatment Plant Corrosion Caused by Citrus and Tomato Acid

equipment with water. Although slightly more expensive, the reclaimed rubber product is particularly attractive since it is a reclaimed product of a pollution problem itself -- old tires.

Solvent Base Latexes

The third class of materials included latexes of nitrile-phenolic copolymers, chloronated polyethylene, vinyl chloride-vinylidene chloride copolymers, a rubber base adhesive, and reclaimed rubber. Impregnation was achieved if sufficiently dilute solutions were used. Because of the relatively large amount of solvent present, however, a good film coating was not obtained on the specimen surface and as a consequence, good corrosion resistance was not achieved. Repeated impregnations would probably offer a solution although this approach was not considered practical. As a result this class was also considered for multiple coatings. As with the water base latexes, the film thickness had to be sufficient to eliminate pinholes. These materials appeared to have excellent resistance to the dilute sulfuric acid. Because of solvent vapors and fumes, as well as the increased cost, they are not as attractive for inplace treatments as the water base latexes. Nevertheless, this class of materials should find limited application in sewer systems.

Liquid Resins

The fourth class of materials included a number of materials in both water and solvent systems, as well as undiluted resin systems. Urea-formaldehyde, urea-formaldehyde-alkyds, melamine-alkyds, phenolics, furans, and epoxies are but several of the materials investigated.

Linseed oil, perhaps one of the oldest concrete treatments, impregnated the concrete in depth, but unfortunately failed to impart any acid resistance. The phenolic and furan resins were somewhat better than the urea-formaldehyde, but even so were only marginally better than the concrete control. The urea-formaldehyde-alkyd resin investigated was considerably better than the straight urea-formaldehydes, but the melamine-alkyd was superior to either of these materials. The principal problem encountered with the melamine-alkyd, however, was the drainage from sharp edges. This same problem was encountered with the epoxies. With few exceptions, the viscosity of the epoxies was too great to allow penetration. The practical problem of pot life makes most epoxies unattractive as impregnants. From the large number of epoxies investigated as coatings, only one (#125) exhibited outstanding acid resistance, and even here, the edges suffered damage. While the epoxy coatings themselves had good

resistance to the sulfuric acid, pinholes in the coating allowed the acid to pass. Once behind the coating, the acid attacked the concrete to the point that after three days' exposure, the epoxy coating usually remained intact but simply separated from the specimen. Thicker coatings or fillers in the epoxy gave mixed results.

The principal difficulty encountered with the resins in this class appears related to the film-forming abilities of the resins. With few exceptions, acid attack on the treated specimens appeared uniform across the surface of the specimen indicating acid penetration through the coating. Of this entire group, certain selected epoxies, the melamine-alkyd, and urea-formaldehyde-alkyd, appeared the most promising, although performance was not as good as for materials from the other classes.

Hot Melts

The last class of materials considered was that of the hot melts, including sulfur, asphalts, coal tars, polyethylene waxes, paraffin, and a gilsonite-asphalt mix. Although not hot melts as such, cut-back asphalt and coal tar pipe dips are also included here, since they were applied heated as well as at room temperature. Impregnation with the hot melts was much better than that of any of the other groups, generally speaking. Inspection of the broken specimens usually revealed complete penetration. The interesting point, however, is the fact that even though impregnation was achieved, with few exceptions, the corrosive attack was about the same or worse than that of the concrete control. Surprisingly, for the degree of penetration obtained by the asphalts, coal tars, and paraffin, the corrosion resistance was poor. The corrosion resistance imparted by impregnation with sulfur was considerably better than that of the other hot melts. Elemental sulfur and certain selected modified sulfur treatments also imparted outstanding strength improvements.

The asphalts and coal tars performed better as coatings than as impregnants, provided adequate thicknesses were employed to reduce pinholes.

Dicussion

In all fairness to the materials investigated and to the manufacturers who supplied them, it must be remembered that the nature of this program was essentially one of screening a large number of materials to select those materials showing the greatest promise, before proceeding to optimize materials and procedures. The fact that most of the materials investigated failed is not as much an indictment of those materials as it

is a demonstration of the severity of attack of 10% sulfuric acid. In all probability, continued investigations with each of the different materials might lead to better selection, modifications, and ultimately an acceptable material. To do this, however, would have required time and expenditures beyond those available.

To recapitulate, from these initial investigations the most promising materials uncovered included HF, SP-4, vinyl-vinylidene chloride copolymer, vinyl acetate-acrylic copolymer, nitrile rubber latex, an emulsified reclaimed rubber, nitrile-phenolic rubber, a rubber base adhesive, a melamine-alkyd resin, one epoxy, and sulfur. The specific test results are summarized for these materials in Table 1 and compared against that of a concrete control.

TABLE 1

PROPERTIES AND CORROSION RESISTANCE
OF PROMISING CONCRETE TREATMENTS

Specimen # and Treatment	Resin Absorption (o/o)	Flexural Strength (psi)	After Exposure to 10% Sulfuric Acid			
			Wt. Loss (g)	Scaling (in/day)	Flexural Strength (psi)	
Concrete Control	-	1160	9.2	.0054	1350	
1 - HF (5% Sol'n)	5.7	1050	2.3	0.00017	1290	
3 - SP-4	5.7	1030	2.7	0	1270	
59 Vinyl - Vinylidene Chloride Copolymer	14.4	1020	0	0	-	**
63 " "	1.7	1260	0	0	-	**
*81 Vinyl Acetate Acrylic Copolymer	7.5	760	0	0	750	
62 Nitrile Rubber Latex	6.3	1270	0	0	-	**
*89 Emulsified Reclaimed Rubber	7.4	550	+1.6	0	980	
*111 " "	3.8	680	+1.5	0	670	
45 Nitrile-Phenolic Rubber	1.2	1260	0	0	1330	
58 Nitrile-Phenolic Rubber/Solvent (50% Sol'n)	0.9	1250	0	0	-	**
126 Rubber Base Adhesive	1.0	1160	+3.7	.0007	1360	
105 Melamine-Alkyd	1.9	1280	+1.3	0	1250	(heat cured)
125 Epoxy	2.5	1310	+1.1	0	1270	
15 Sulphur	9.7	2970	6.9	0	2890	
17 Modified Sulphur	8.8	2800	5.1	.0005	1770	

* Specimens prepared from 8" dia. concrete pipe, rather than 6" dia. pipe.

** No data taken

SECTION VII

OPTIMIZATION OF MATERIALS AND PROCEDURES

Although discussed separately, the optimization of materials and procedures was actually integrated into the program. As the performance of the materials was being evaluated, manufacturers would supply additional materials, modifications would be made, or impregnating or coating techniques would be varied in attempts to improve performance. These materials or modifications of materials have been included in the respective sections of Appendix A.

With the water soluble salts and acids, optimization included varying concentrations, or combinations of materials. With the water base latexes, several anionic surfactants were investigated, along with the use of wet and dry specimens. Although the use of the surfactants did not necessarily improve the corrosion resistance, the surfactants did improve the bonding of some latexes to the concrete. Dry concrete specimens generally caused the gellation of a thicker latex film than did the wet specimens. When applying the latexes as a coating over the dry specimens, there appeared to be more pinholing on the initial coat due to the escape of the air, whereas with the wetted specimens, this problem was not as pronounced. This is of definite benefit when considering the coating of installations in-place since the walls in these installations are usually damp or wet from condensate or capillary water.

One technique that proved useful in the coating applications was the use of multiple coatings for both the water base and solvent base latexes. This included the use of a primer coat followed by one or more layers of the latex coat. In most cases a primer coat of nitrile-phenolic latex improved adhesion of the finish coat. With the multiple coatings, two layers were better than one, and three appeared to be the optimum. While the corrosive attack with single coatings was not always measurable, pinholes did appear, whereas additional coatings eliminated them completely.

One other technique that improved the performance of some coatings was the use of filler material, particularly plate-shaped particles such as talc.

In addition to the techniques already mentioned, when using the hot melts, particularly asphalt and coal tar, heated and room temperature specimens were employed. The heated specimens allowed for more drainage and thus thinner coatings, particularly at the sharp edges. As a result the

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room temperature specimens had thicker coatings and better corrosion resistance.

A double treatment employing two promising systems was also investigated. Hence, specimens treated with HF were also impregnated with sulfur and coal tar. Other specimens were impregnated with sulfur for the strength improvement and then coated with latex. The double treatment, although more costly than a single treatment, was definitely better and should be considered where extremely severe conditions might be expected. Table 2 lists the most promising double treatments investigated.

Of the materials investigated on this program, sulfur was the most promising material that imparted considerable strength improvement to the concrete. Since both sulfur and the concrete pipe must be heated in order to obtain impregnation, experiments were conducted wherein the optimum times, temperatures and conditions were determined for optimum strength.

The first consideration when heating concrete to elevated temperatures is the age of the concrete itself. Even though concrete pipe has cured sufficiently in one day to be handled and moved, the strength continues to grow with time. Usually the nominal strength is obtained within several days as shown in Figure 10. It is interesting to note that even though the strength of the pipe has plateaued at about five days, considerably better strengths were obtained by impregnating with sulfur only after 20 days. The specimens used for the 180 day test are from a different batch of pipe, however, from the data, this appears to be of little significance.

The second consideration was that of the temperature at which impregnation would be carried out. Previous investigations using elemental sulfur (18, 19) have shown that the time - temperature history of the sulfur is very important in obtaining optimum mechanical properties. For example, in one study it was found that the maximum tensile strength was obtained from specimens prepared at approximately 150°C. This phenomenon has been related to the allotropic modifications of sulfur under these temperature conditions. To determine the effects of temperature on the impregnated concrete, the temperature of the sulfur was varied between 130°C (slightly above the melting point of sulfur) and 160°C (the temperature at which sulfur becomes very viscous.) This data is presented in Figure 11. The maximum strength is obtained at approximately 150°C.

The final consideration of impregnating with sulfur is the process conditions necessary for impregnation. The use of vacuum or partial vacuum

TABLE 2

PERFORMANCE OF SELECTED DOUBLE-TREATED SPECIMENS

Specimen	After Exposure to 10% H_2SO_4			
	Wt. Loss (g)	Scaling (in./day)	Flexural Strength (psi)	
68 HF Impregnated followed by Coal Tar Impregnation	+1.9 *	0	---	**
69 HF Impregnated followed by Sulfur Impregnation	+2.6	0	2300	
131 Sulfur Impregnated coated with Vinyl-Vinylidene Chloride	+2.5	0	2080	
132 Sulfur Impregnated coated with Nitrile-Phenolic Latex	0	0	---	
133 Sulfur Impregnated coated with Rubber Adhesive	0	0	---	
134 Sulfur Impregnated coated with Reclaimed Rubber Emulsion	0	0	---	
135 Coal Tar over Primer Coat	0	0	---	

* Plus Sign Indicates Wt. Gain

** Dash Line Indicates No Data Taken

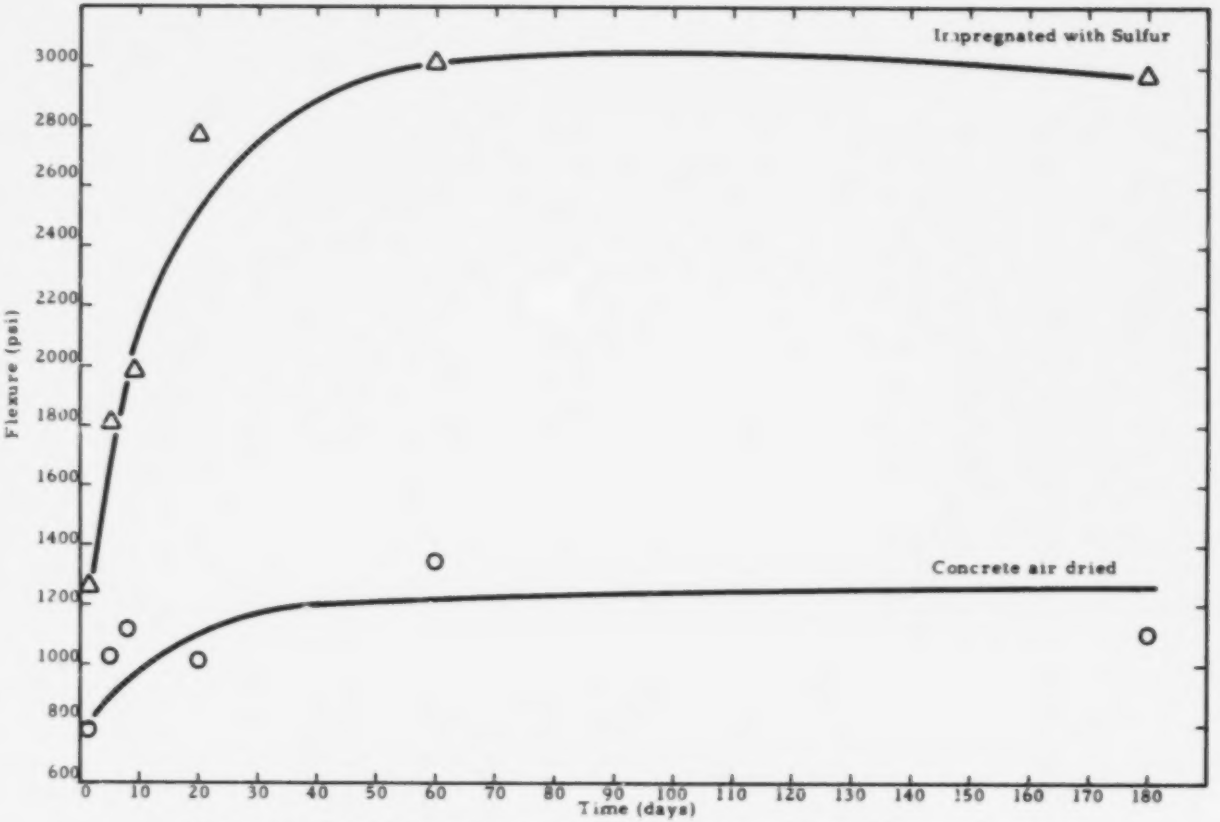

Figure 10. Flexural Strength as a Function of Pipe Age for Sulfur Impregnated Concrete.

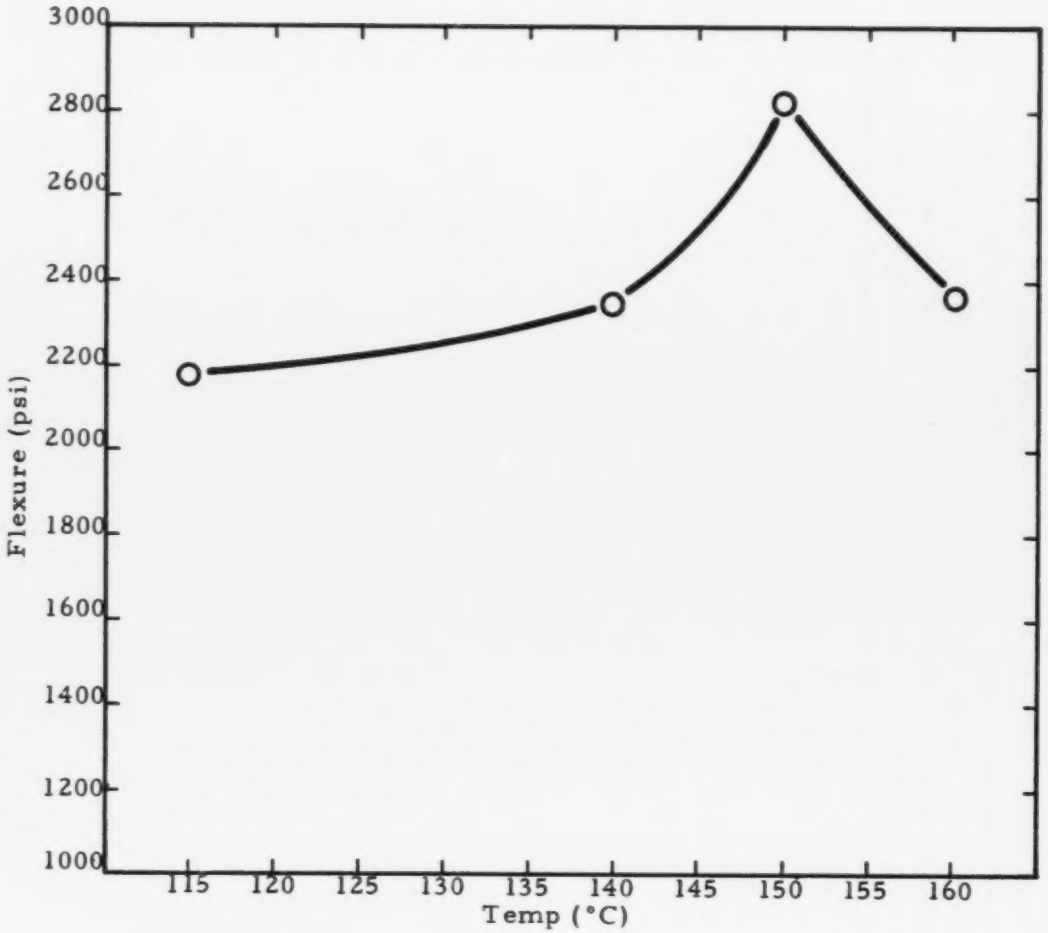

Figure 11. Flexural Strength of Impregnated Concrete as a Function of Sulfur Temperature

necessarily limits a process to a batch type operation. Pressure, however, can be related to a liquid pressure head, and if one envisions a deep vat filled with impregnating liquid, the pipe can be submerged to an appropriate depth for a specific period of time and be automatically placed and removed, as with a conveyor belt. To determine the effect of pressure only, specimens were submerged under liquid sulfur and then an air pressure of 30 psig was applied for time periods ranging from 5 to 30 minutes. The quantity of sulfur impregnated into the concrete as well as the flexural strength was then determined and is reported in Table 3. From the data, although there was a continual increase in sulfur absorbed by the concrete, the strength is fairly constant, indicating that 5 to 10 minutes under this pressure is sufficient. For operation at a lower pressure head, a longer impregnation would no doubt be required.

TABLE 3

ABSORPTION AND STRENGTH OF SULFUR IMPREGNATED CONCRETE PIPE AT 30 psig PRESSURE

Time (min.)	Absorption (%)	Flexural Strength (psi)
5	7.4	2120
10	7.4	1730
15	7.7	2080
20	8.0	2020
25	8.4	1810
30	8.9	2530

SECTION VIII

PRELIMINARY FIELD TESTS

Once several promising materials had been developed, it was decided that limited experiments would be conducted in active sewer lines. While acid attack was readily simulated in the laboratory on an accelerated rate, correlation with that experienced in a sewer line is difficult. For example, films and coatings can be totally impermeable to liquids, but not to gases. Thus it was possible that even though the coatings investigated showed excellent resistance to sulfuric acid, when subjected to a sewer environment the hydrogen sulfide, water vapor, and air, could penetrate these coatings and cause corrosion behind the coating. Another unknown was the effect that bacteria would have on the treatments, particularly sulfur and the latex coatings.

Eight specimens were prepared and placed in an influent diversion box at Harlingen, Texas on November 6, 1970. The gases in this diversion box are extremely corrosive and this particular box had just been rebuilt because of failure by concrete corrosion. The eight specimens placed in Harlingen were prepared from six inch inside diameter concrete pipe and were each approximately six inches in length. The weights were recorded before being suspended in the diversion box. A brief description of each specimen follows:

A. Control

B. Coated with a water emulsified reclaimed rubber

C. Coated with nitrile-phenolic rubber diluted 30% with toluene

D. Coated with a synthetic rubber adhesive in a solvent system

E. Coated with a vinyl acetate-acrylic copolymer in a water emulsion.

F. Coated with a vinyl chloride-vinylidene chloride copolymer in a water emulsion

G. Impregnated with elemental sulfur

H. Chemically treated with a 5% hydrofluoric acid solution

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On February 15, 1971 one additional specimen was placed in Harlingen. This specimen was impregnated with sulfur containing 0.5% by weight sodium pentachlorophenate, an effective bactericide for sulfur. (20)

On December 8, nine specimens were placed in a siphon station in the southeast part of San Antonio which has had a long history of hydrogen sulfide corrosion. The concrete interior of this station is badly corroded from the corrosive gases. The specimens were placed on a walkway above the liquid level but condensate collects readily on the walls, the walkway, and the specimens. The nine specimens placed in San Antonio were prepared from 6-in. inside diameter concrete pipe and were each approximately 6 in. in length, and with the exception of the ninth specimen, were identical to those prepared for the Harlingen site.

A. Control

B. Coated with a water emulsified reclaimed rubber

C. Coated with nitrile-phenolic rubber diluted 30% with toluene

D. Coated with a synthetic rubber adhesive in a solvent system

E. Coated with a vinyl acetate-acrylic copolymer in a water emulsion

F. Coated with a vinyl chloride-vinylidene chloride copolymer in a water emulsion.

G. Impregnated with elemental sulfur

H. Chemically treated with a 5% hydrofluoric acid solution

I. Coated with a reclaimed rubber-solvent system

Also, on December 8, 1970, three specimens were submerged in one of the active septic tanks on the Institute grounds. These specimens were prepared from 6-in. inside diameter concrete pipe and were approximately 3 in. in length. The first specimen was a control, the second specimen was impregnated with elemental sulfur, while the third specimen was impregnated with elemental sulfur containing 0.5% by weight of the bactericide sodium pentachlorophenate. The purpose of these tests was to determine the relative attack of the bacteria on concrete impregnated with sulfur and the effect of bactericide in a sulfur system. It would appear

that a bactericide is a simple solution to the bacterial attack on sulfur experienced in the past. (20-22)

Within one week, the concrete control in the septic tank began to discolor, indicating a chemical reaction occurring between constituents in the concrete and the sewage. A check of the specimens in the siphon station in San Antonio indicated this same reaction with the concrete control was occurring in the air space, although not as severe. Subsequent inspection revealed identical staining of the control specimen in Harlingen. Hydrogen sulfide or soluble sulfide salts were suspected and subsequent laboratory experiments confirmed this. Concrete specimens were subjected to a 10% solution of sodium sulfide as well as to a hydrogen sulfide gas atmosphere. The discoloration or staining was observed in each instance and is attributed to a reaction between the sulfide and iron present in the cement. When submerged in a 10% sodium sulfide solution for 3 days, discoloration occurred throughout the specimen. When suspended in a hydrogen sulfide gas atmosphere for one week, staining had penetrated to an average depth of 0.12 in., but in some areas as much as 0.25 in. To test the theory that an impregnant, by blocking the voids, should eliminate penetration of liquid or gas, one specimen impregnated with sulfur was submerged one week in a 10% solution of sodium sulfide. Cutting the specimen revealed that only the surface of the specimen was discolored, and penetration of the liquid had not taken place. Likewise a specimen impregnated with sulfur suspended in a hydrogen sulfide gas atmosphere showed only slight discoloration on the surface but no penetration. Figure 12 is a photograph showing the staining and protection afforded by impregnation, when subjected to a 10% sodium sulfide solution. The specimen on the left is a concrete control, while the center specimen, which is the concrete control submerged in sulfide solution, shows the discoloration throughout the cross-sectional area. The specimen on the right shows a surface staining but the cross-sectional area is unstained, indicating that the sulfur blocked the pores and eliminated penetration.

Although the specimens were exposed in the field tests for approximately four months, they were winter months when acid generation is at a minimum. The concrete control specimen in Harlingen is beginning to show signs of corrosion. The entire specimen is covered with a white, frangible efflorescent coating typical of sulfate formation. The control in the siphon station in San Antonio is showing slight efflorescence and one specimen coated with the vinyl-vinylidene chloride emulsion has several pinholes. All other specimens in San Antonio and Harlingen are showing no signs of corrosion.

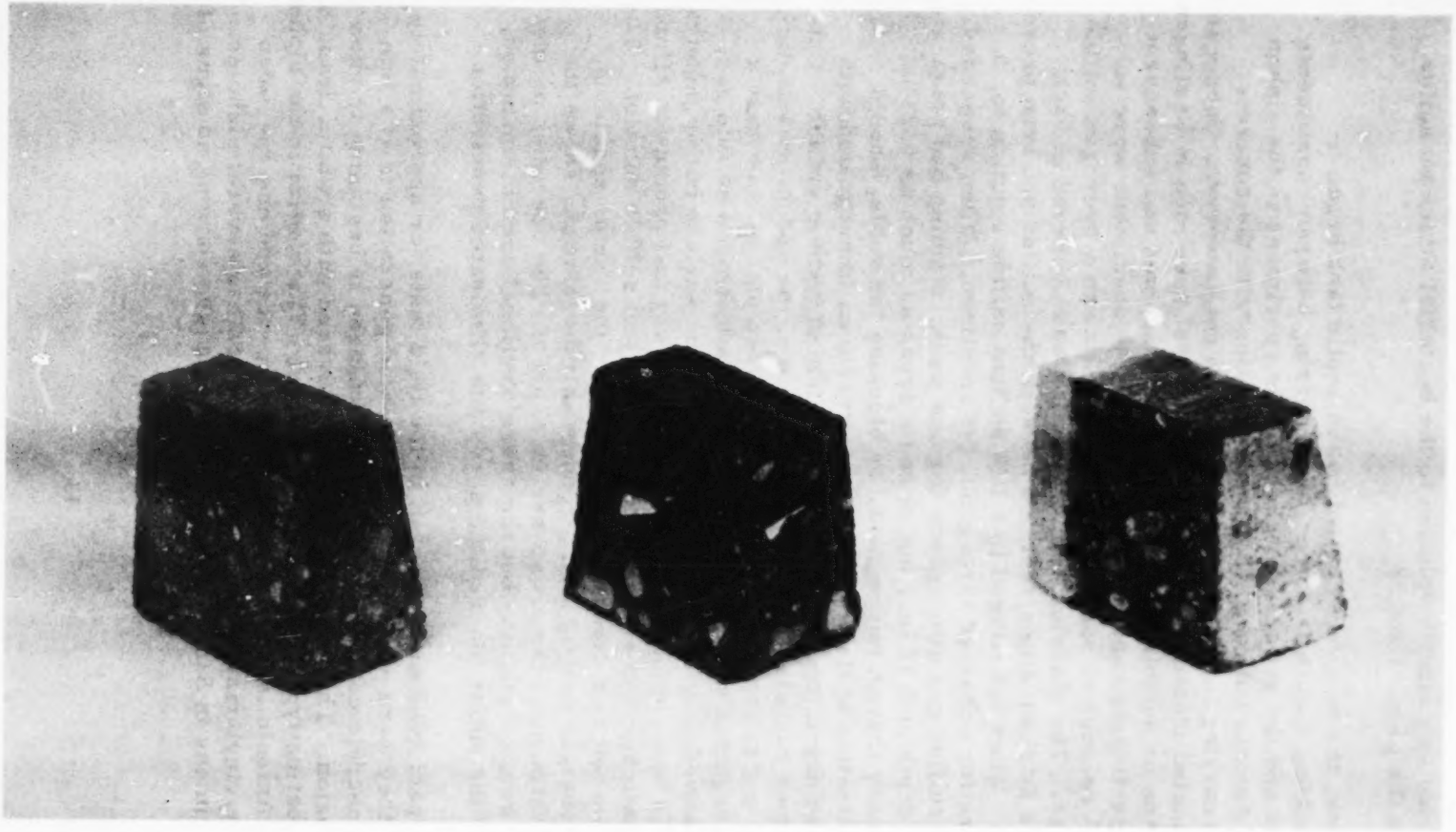

Figure 12. Staining of Concrete by Sodium Sulfide Solution

SECTION IX

SIGNIFICANCE OF LABORATORY AND FIELD FINDINGS

As described in detail earlier, 10% sulfuric acid causes the most severe attack on concrete. Typical maximum concentrations of approximately 5% as found in sewers are also severe. As severe as this attack is, however, it is tempered by the fact that although maximum concentrations of 5% have been measured in sewers, during the cooler months this concentration drops considerably so that the most severe attack reported (3) in sewers is approximately 1/2 in. /yr. (0. 0014 in. /day) wall loss, very nearly the same as that of limited laboratory tests of a 1% solution of sulfuric acid with scaling rates of approximately 0. 0015 in. /day. If further correlation studies can indeed verify that a 1% sulfuric acid solution can simulate the most severe attack encountered in sewer lines, then a very valuable laboratory tool will have been established for determining and predicting sewer pipe life.

The second interesting point as relates to sulfuric acid attack in laboratory tests is the fact that for all concentrations the attack is limited to the surface. Attempts using vacuum and pressure failed to cause any sulfuric acid to penetrate the concrete any deeper than 1/8 in. from the surface. This is attributed to the fact that the sulfate and sulfo-aluminate products have larger crystal volumes than the reactants and as such tend to seal or block the passages. As this protective coating falls away, the attack progresses into the specimen. Figure 13 shows the surface attack typical of sulfuric acid action in the laboratory test. Limited specimens taken from sewers indicate this type of attack is also typical of the attack found in some concrete sanitary sewers.

Hydrogen sulfide or sulfide solutions readily penetrate concrete. To what extent this plays in the corrosion process has not been determined. References to this occurance have not been uncovered in the literature. The fact that sulfuric acid seals the surface, may eliminate or minimize attack in this manner. The fact that impregnated specimens were not penetrated by the sulfides is most encouraging.

Another point of major significance relates to the performance of the most promising systems developed. The scaling rate as determined for the various systems is a valuable aid since it not only gives an indication of the relative performance of the different systems, it also allows for a prediction of the life of the treated pipe of known wall thickness. While the hazards of predicting pipe life based only on the laboratory findings

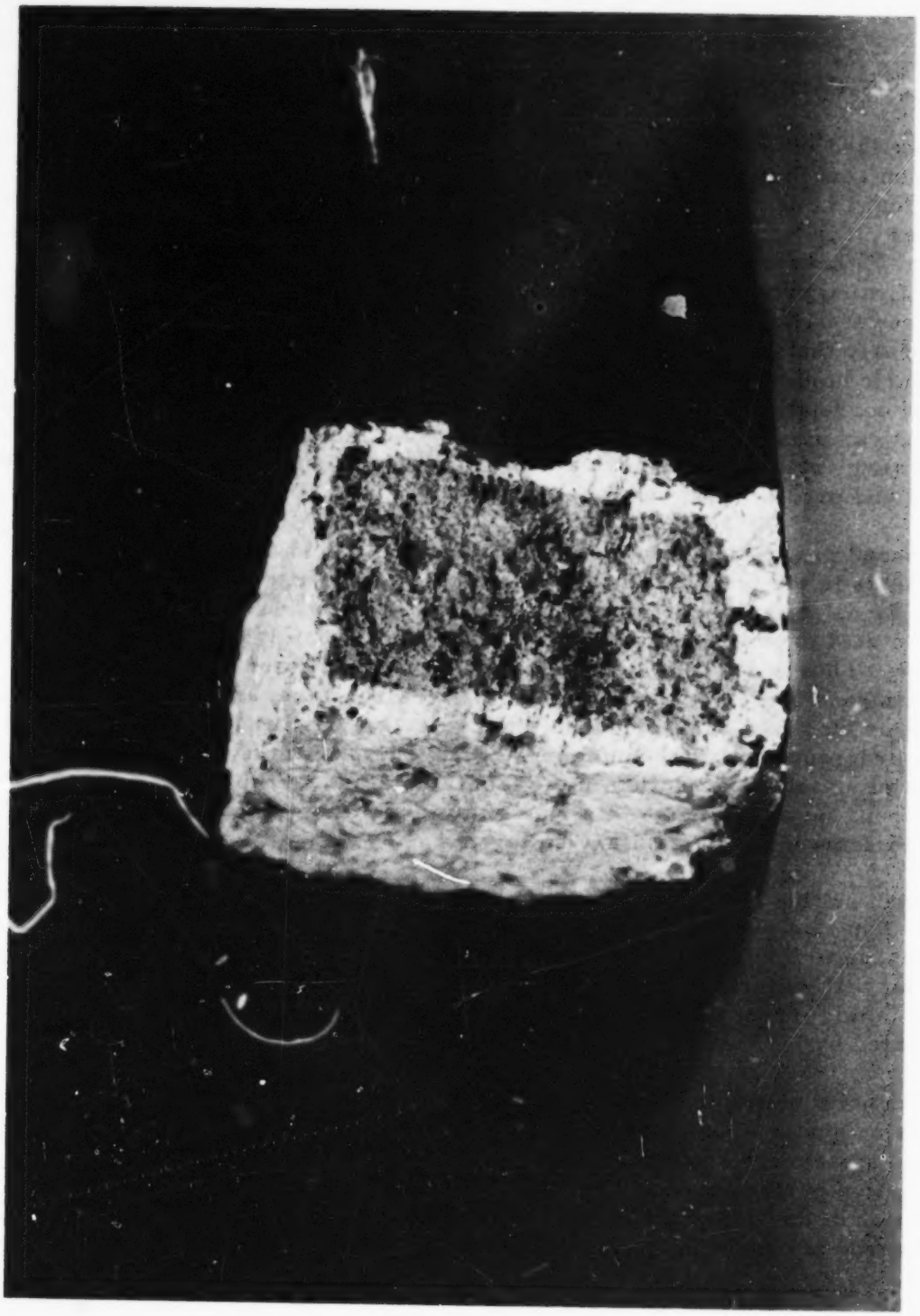

Figure 13. Surface Attack of Sulfuric Acid

are fully realized, it is recognized that the acid test conditions of the laboratory are much more severe than those encountered in the field. It must be emphasized that considerably more field data have to be obtained for good correlations, however, some conservative estimates can still be made. As already pointed out, the most severe corrosion measured in a sewer line has been as much as 1/2 in. /yr, or approximately 0.0014 in. /day. Thus a pipe having a wall thickness of 1 inch would be consumed in 2 years. This rate of attack is obtained in the laboratory with a 1% solution of sulfuric acid. When using 10% solutions of sulfuric acid, the scaling rate for the concrete control averages 0.0054 in. /day or approximately 3.8 times greater than the most severe cases found in sewer lines.

Although most of the better treatments did not have a measurable scaling rate, as indicated in Tables 1 and 2, continued exposure should produce a measurable rate after an extended time. For the coating alone, once the coating has failed, corrosion of the underlying concrete should proceed at the same rate as unprotected concrete, hence the useful life of the coating systems is difficult to assess. For the materials with measurable scaling rates, however, estimates of useful life can be made.

From Table 1, specimen No. 17, which was impregnated with modified sulfur, had a laboratory scaling rate of 0.0005 in. /day. The concrete control has a laboratory scaling rate of 0.0054 in. /day. Thus, the sulfur impregnated pipe is approximately 10 times better than concrete according to the laboratory tests. Thus, as a conservative estimate, impregnated pipe with a wall thickness of 1 inch would be consumed in 20 years rather than 2 years. If the fact is considered that the laboratory tests are 3.8 times more severe than that of actually measured sewer values, then it would take 76 years to consume the pipe.

As another example, from Table 1, specimen No. 1, which was impregnated with hydrofluoric acid, has a measurable laboratory scaling rate of 0.00017 in. /day or approximately 30 times better than the laboratory scaling rate of concrete. Thus a pipe of 1 inch wall thickness would be consumed in 60 years as a conservative estimate, or 228 years using the factor of 3.8.

Pipe with wall thicknesses greater than one inch would take proportionately longer to be consumed. The fact that many of the better systems had scaling rates of 0 after 3 days in 10% sulfuric acid indicates that their ultimate scaling rate might be better than those used in the two examples above.

The final point of significance from this program's findings is the possibility of in-service treating of lines using the hydrofluoric acid treatment. Essentially this would entail a low pressure acidizing process very similar to oil and gas well acidizing which is carried out routinely in the petroleum industry.

SECTION X

ECONOMICS

It is estimated that nearly 90 million linear feet of concrete pipe are manufactured annually. Its low cost, ease by which it can be manufactured and its attractive physical properties all play a role in its popularity. Whenever pipe other than concrete is used in sewer applications, the additional cost is usually justified because of the improved corrosion resistance of the other type pipe, although weight considerations can sometimes be important. Figure 14 is a graph showing San Antonio selling prices for the various types of sewer pipes available. While selling prices may vary somewhat from locality to locality, these figures are representative of the relationships between the different types of sewer pipe. All of the prices reflected in Figure 14 were obtained from local manufacturers or suppliers, except for the vinyl chloride lined/epoxy-coal tar lined pipe. This curve area was calculated by adding to the cost of reinforced concrete pipe $0.60 to $0.75 for materials cost and $0.15 to $0.25 for labor per square foot of treated concrete pipe. The material and labor costs were obtained from lining and pipe manufacturers and reflect typical additional costs. Thus, in order for impregnated concrete pipe to be accepted, it must have a cost effectiveness better than the other types of pipe.

In discussing the economics of potential treatment systems the predicted treatment costs are general figures since further processing studies are needed to generate firmer economic figures. Nevertheless, these estimates give a good indication of the relative economics.

To impregnate or treat sewer pipe, two extreme cases have been selected and the economics calculated. The first case envisions a rather simple automated process, requiring a minimum of hand labor. In this process the impregnation vat would operate at atmospheric pressure on a continuous automated basis. For the hot melts, this vat would in many ways resemble a typical sulfur melter or Frasch sulfur mine relay station. The rectangular pit or tank of steel or concrete would be lined with steam heating coils of Schedule 80 black steel pipe. Material make-up to the pit would be supplied from either a molten storage tank or by melting material on site. One simple design for a sulfur melter consists of laying steam piping on a concrete apron sloped into the pit. Sulfur or the other materials would be stockpiled on the apron. When additional material is required, steam is circulated through the pipes and the melted material drains into the pit. Temperature of the molten material would be automatically

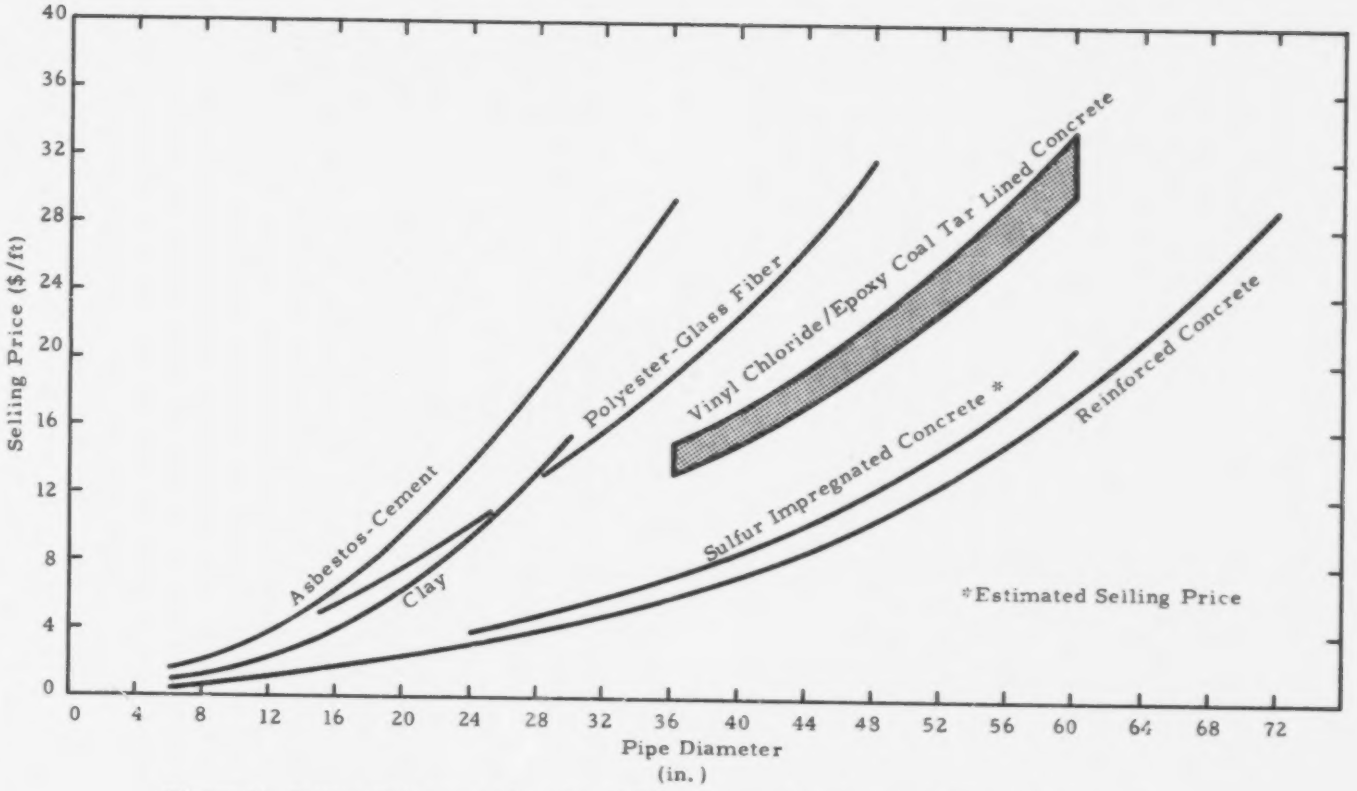

Figure 14. Selling Price as a Function of Pipe Diameter for Various Types of Sewer Pipe

controlled by regulating the steam pressure. Conveyors could be used for moving the pipe into and out of the pit. For impregnation materials not requiring heat, the steam lines would be eliminated. This type of operation should represent a very low impregnation cost.

The second process assumes almost exclusive hand labor such as required in autoclaving the pipe on a batch basis. Typical labor costs are generally a maximum of $\$0.25/ft^2$ of treated surface. This cost was used in calculating the costs under the hand labor columns in Table 4. The cost of impregnating concrete pipe with sulfur is reported for both types of processes. The automated column assumes that the pipe could be handled and treated for essentially the same costs that the Frasch sulfur producers can mine the sulfur by heating with superheated water a massive limestone formation several thousand feet below ground surface, melt the sulfur, pump it to the surface, store it, and finally sell it at a profit for $\$0.01$/lb. This cost should reflect the projected minimum cost. The maximum projected cost is represented by having to use hand labor methods of a batch process.

The hydrofluoric acid treatment was viewed essentially as a materials handling process since heat is not required. The typical selling price for crushed aggregate is approximately $\$2.00/yd^3$. This includes mining or blasting, crushing, washing, and screening to specifications. As seen in Table 4, the hydrofluoric acid impregnation costs are slightly less but of the same magnitude as those for sulfur impregnation.

The coating costs as represented by the latexes assume hand labor with spray equipment similar to that currently used in lining concrete pipe, and were computed for actual film thicknesses used in the laboratory for adequate acid protection. As can be seen, the labor accounts for the major portion of the cost. These types of coatings, however, should find acceptance more readily in treating in-place structures such as treatment tanks, junction boxes, wet wells, etc. More detailed calculations are reported in Appendix B.

From an economic point of view, impregnation or treatment of concrete pipe with either sulfur or hydrofluoric acid appears very attractive with substantial savings over other types of pipe as well as lined concrete pipe. From the laboratory studies and preliminary field studies, the projected service life of these two treatments is certainly encouraging. Because of these facts, the next major step in this program should be one of extended field tests, paralleled by continued laboratory study to further develop a correlation between the laboratory and field data, so that

TABLE 4

Relative Economics of Treating Concrete Pipe

Pipe Diameter (in.)	Hand Labor Costs for Current Coatings ($/linear ft)	Cost Differential Above the Cost of Concrete Pipe ($/Linear ft.)					
			Impregnation			Coating	
		Clay/ Polyester-Glass Fiber	Sulphur at $0.01/lb Automated	Sulphur at $0.01/lb Hand Labor	HF (5% Solution at) at $0.015/lb	Vinyl-Vinylidene Chloride at $0.18/lb	Reclaimed Rubber at $0.40/lb
18	1.18	3.50	.35	1.35	.22	1.18	1.30
24	1.57	8.00	.55	1.85	.35	1.89	2.08
30	1.96	11.00	.76	2.34	.47	2.36	2.60
36	2.36	13.00	1.05	2.88	.65	2.84	3.13
48	3.14	20.00	1.72	4.00	1.08	3.79	4.16
60	3.92	12.00 *	2.59	5.22	1.62	4.73	5.20

* Plastic Lined Concrete

optimum treatment systems can be developed with predictable service lives. Once an optimum system is determined, a specific process design can be undertaken and the economics can be established on a very accurate basis.

SECTION XI

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SECTION XIII

APPENDICES

		Page
A.	Part A - Water Soluble Salts and Acids	61
	Part B - Water Base Latexes	62
	Part C - Solvent Base Latexes	65
	Part D - Resins	66
	Part E - Hot Melts	69
B.	Detailed Materials Cost and Impregnation or Coating Costs	73

APPENDIX A

Properties and Corrosion Resistance of Impregnated Concrete

Part A - Water Soluble Salts and Acids

Properties and Corrosion Resistance of Impregnated Concrete

Specimen #*	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4		
			Wt. Loss (g)	Scaling (in./day)	Flexural Strength Room Cured (psi)
Control	----	1160	9.2	.005	1350
1 Hydrofluoric Acid (5%)	5.7	1050	2.3	.00017	1290
2 Hydrofluosilicic Acid (2.7%)	0.54	1090	10.7	.007	1010
3 SP-4	5.7	1030	2.7	0	1270
4 Sodium Silicate	1.5	1130	8.1	.004	-- **
19 10% H_3PO_4	2.4	1520	12.2	.006	1150
21 10% Zn Si F_6	4.3	1140	8.2	.0018	1170
22 10% MgSI F_6	2.7	1330	8.2	.0018	1320
23 5%/5% Zn/Mg $(Si\ F_6)_2$	3.5	1390	8.6	.0008	1240
29 Oxalic Acid	4.2	1210	9.0	.0008	1190
48 10% H_3PO_4 (500°C Cure)	-2.4	1140	9.2	.0063	730
49 10% Sodium Fluoride	5.6	1400	7.2	.001	1280
50 10% Sodium Hexa-metaphosphate	3.8	2160	11.4	.0003	1320
52 5.5% Superbond	4.9	1110	10.2	.0027	1170
53 Superbond	7.3	1360	7.7	.0013	1080
56 10% Boric Acid	6.6	1300	5.3	.0017	1140
80 98% H_2SO_4	Attacked Aggregate Only			0	--
127 Hydrofluosilicic Acid (1%)	0.9	1030	9.2	.005	1060
128 Hydrofluosilicic Acid (0.5%)	1.8	825	8.2	.003	1410
129 Hydrofluosilicic Acid (0.1%)	1.9	1080	10.6	.003	1000

*Specimen number as permanently recorded in the laboratory notebook.
**Dashed line indicates data not taken.

Part B - Water Base Latexes

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4		
			Wt. Loss (g)	Scaling (in./day)	Flexural Strength Room Cured (psi)
41 Silicone Latex	5.3	1480	6.3	.0023	1290
42 Butadiene/Styrene Latex	6.2	1330	9.7	.0013	1290
44 Natural Rubber Latex	4.3	1030	8.9	.0009	1220
59 Vinyl Chloride-Vinylidene Chloride	14.4	1020	0	0	--
60 Vinyl Chloride-Acrylic	8.5	1070	0	0	1010
61 Vinyl Chloride-Acrylic	5.8	1270	12.0	.009	1030
62 Nitrile Rubber Latex	6.3	1270	0	0	--
63 Vinyl Chloride-Vinylidene Chloride	1.7	1260	0	0	--
77 Acrylonitrile Latex	1.7	840	3.2	.0015	1190
78 Acrylonitrile Latex	2.2	1200	+1.7*	.0007	1190
79 Vinyl Chloride - Acrylic	3.2	880	17.2	.0018	890
81 Vinyl Acetate - Acrylic	7.5	760	0	0	750
82 Vinyl Acetate - Acrylic	6.2	710	0	0	700
83 Polyvinyl Acetate	3.7	930	+1.3	0	810

*(+ sign indicates wt. or dimension gain)

Part B - Water Base Latexes (cont'd)

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4		
			Wt. Loss (g)	Scaling (in./day)	Flexural Strength Room Cured (psi)
84 Acrylic	3.3	740	0	.0026	790
85 Vinyl Chloride-Acrylic	1.9	710	+2.8	.0008	870
86 Vinyl Chloride-Vinylidene Chloride	2.1	500	+4.7	+.005	750
87 Vinyl Chloride-Acrylic	1.3	980	8.0	.0017	950
88 Acrylonitrile	2.4	290	+1.0	0	710
89 Reclaimed Rubber	7.4	550	+1.6	0	980
110 Vinyl-Vinylidene Chloride and Surfactant	9.6	1050	+1.4	+0.005	1170
111 Reclaimed Rubber	3.8	680	+1.5	0	670
112 Reclaimed Rubber (over nitrile-phenolic tack coat)	7.7	790	0	0	715
114 Vinyl Acetate-Acrylic (over nitrile-phenolic tack coat)	2.2	875	+2.3	0	720
115 Vinyl Chloride-Vinylidene Chloride (over nitrile-phenolic tack coat)	1.3	965	+3.7	0	850

Part B - Water Base Latexes (cont'd)

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4		
			Wt. Loss (g)	Scaling (in. /day)	Flexural Strength Room Cured (psi)
116 Nitrile Latex	8.8	765	13.3	.0027	1070
120 Vinyl Chloride-Vinylidene Chloride and Surfactant	5.2	1560	1.1	.0021	960
123 Reclaimed Rubber (Water base)	2.1	1090	+2.1	0	1050
130 Modified Vinyl-Vinylidene Chloride	5.7	--	+4.0	+.007	850

Part C - Solvent Base Latexes

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4		
			Wt. Loss (g)	Scaling (in. /day)	Flexural Strength Room Cured (psi)
43 Nitrile-Phenolic Rubber	0.8	1710	7.6	.0005	1360
45 Nitrile-Phenolic Rubber (Brushed on)	1.2	1260	0	0	1330
54 50% Nitrile-Phenolic Rubber/Solvent	0.9	1050	5.1	.0022	1160
58 50% Nitrile-Phenolic Rubber/Solvent (Oven dried)	0.9	1250	0	0	--
64 Nitrile-Phenolic	0.9	1 coat	0	0	Moderate resistance
65 Rubber in	1.6	2 coats	0	0	Good resistance
66 50% Solution of	2.4	3 coats	0	0	Extremely good resistance
67 methyl ethyl ketone	3.5	4 coats	0	0	Extremely good resistance
71 Chloronated Poly-ethylene	1.8	1500	11.1	.007	1180
124 Reclaimed Rubber (Solvent base)	0.7	1250	6.4	.001	1100
126 Rubber Adhesive	1.0	1160	+3.7	.0007	1360
137 30% Solution of Vinyl-Vinylidéne Chloride in Toluene		1 coat		Poor Resistance	
		2 coats		Poor Resistance	
		3 coats		Fair Resistance	
138 30% Solution of Vinyl-Vinylidene Chloride in Toluene with 2% Talc		1 coat		Fair Resistance	
		2 coats		Fair Resistance	
		3 coats		Excellent Resistance	

Part D - Resins

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4			
			Wt. Loss (g)	Scaling (in. /day)	Flexural Strength Room Cured (psi)	Flexural Strength Heat Cured (psi)
5 Urea Formaldehyde	1.4	1170	7.6	.0013	1080	1190
6 Silicone	7.1	1340	8.1	.0047	1400	--
7 Silicone	4.8	1095	9.6	.0067	1260	--
8 Furan Resin	2.6	950	9.7	.0015	1110	1080
9 Linseed Oil	2.6	1380	11.9	.0067	1510	1820
10 Urea-Formaldehyde	5.7	1290	11.5	.0068	--	1250
11 Urea-Formaldehyde	1.0	1600	8.1	.0047	990	1260
12 Phenolic Resin	1.2	1880	4.8	.0012	1530	1580
13 Urea-Formaldehyde	0.94	1570	8.1	.0073	1400	1420
14 Urea-Formaldehyde	0.66	1670	6.7	.003	1300	1830
24 Acrylic	1.8	1590	7.3	.005	1580	--
25 Alkyd Traffic Marking Paint	3.8	1540	7.4	.0019	1250	--
26 Acrylic Wax	1.0	1280	8.7	.004	1350	--
27 Modified Urea-Formaldehyde	4.8	1560	9.4	.0008	1190	--
28 Tung Oil	1.9	1560	11.2	.0007	1160	--
31 Modified Phenolic Resin	1.3	1640	7.2	.002	1410	--
39 Resin Oil A	4.2	1380	8.7	.0018	1210	--
40 Resin Oil B	1.6	1560	9.8	.0028	1420	--
46 Resin Oil B (Oven dried)	0.8	1230	9.2	.0033	--	1120
47 Resin Oil A (Oven dried)	1.5	1090	6.6	.0033	--	1180

Part D - Resins (cont'd)

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4			
			Wt. Loss (g)	Scaling (in./day)	Flexural Strength Room Cured (psi)	Flexural Strength Heat Cured (psi)
55 50% Urea Formaldehyde in Toleune	3.0	3030	9.1	.003	1380	--
57 Flexible Epoxy	5.3	1360	8.9	.005	1310	--
74 Alkyd Resin	1.8	1420	20.5	.006	1370	--
90 Rigid Epoxy	4.9	1330	+2.7	+0.002	1310	--
91 Flexible Epoxy	9.5	1020	13.2	.0037	880	--
92 Rigid Epoxy	No penetration					
93 Flexible Epoxy	No penetration					
94 Rigid Epoxy	1.9	1660	+0.5	+0.0017	1280	--
95 Flexible Epoxy	2.4	1330	14.0	0.0013	1170	--
96 Rigid Epoxy	5.5	3150	+1.5	+0.0027	2480	--
97 Flexible Epoxy	8.3	2560	21.7	0.0023	1460	--
98 Epoxy	3.8	1180	+5.6	+ .0043	1310	
99 Epoxy	7.1	1360	+7.2	.0007	920	--
100 Epoxy	1.5	1230	5.0	.0017	1060	--
101 Epoxy	2.7	1010	5.1	0.0015	765	--
102 Epoxy	Solution boiled over -- No penetration					
103 Furan	7.9	685	0	0.0013	1000	
104 Furan	4.6	915	0.6	0.0022	1000	--
105 Melamine-Alkyd (coating only)	1.9	1280	+1.3	0	--	1250
107 Melamine-Alkyd	2.7	1380	12.1	0.0013	--	1200
109 Melamine-Alkyd (coating only)	1.3	1300	3.4	0.0022	900	--
117 Butadiene-Furfural	1.9	730	10.4	0	--	965
118 Urea-Formaldehyde-Alkyd	2.2	1410	7.4	.0008		1330

Part D - Resins (cont'd)

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4			
			Wt. Loss (g)	Scaling (in./day)	Flexural Strength Room Cured (psi)	Flexural Strength Heat Cured (psi)
119 Urea-Formaldehyde-Alkyd (coating only)	2.0	1115	3.7	.003	--	1000
121 Urea-Formaldehyde-Alkyd (coating only)	1.6	1090	11.4	.007	--	945
122 Urea-Formaldehyde-Alkyd (coating only)	1.5	1010	13.4	.005	1150	--
125 Epoxy	2.5	1310	+1.1	0	1270	

Part E - Hot Melts

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4		
			Wt. Loss (g)	Scaling (in./day)	Flexural Strength Room Cured (psi)
15 Sulfur	9.7	2970	6.9	0	2890
16 Cut back Asphalt	5.0	1590	16.2	.0097	1690
17 Plasticized Sulfur	8.8	2800	5.1	.0005	1770
18 Modified Sulfur	6.6	1650	5.7	.0008	2230
20 Paraffin	4.0	2030	9.4	.006	1720
30 Asphalt	0.75	1730	9.1	.003	1300
32 Modified Sulfur	9.8	2690	7.0	.0015	1980
33 Modified Sulfur	7.8	1970	7.1	.0017	2260
34 Polyethylene Wax	1.1	1350	7.9	.0018	1320
35 Same as 33 with coating	9.0	2570	6.4	.002	2310
36 Polyethylene Wax/ Paraffin	1.9	1720	9.2	.0025	1290
37 Coal Tar Pipe Dip	4.8	1700	10.1	.0016	1310
38 Coal Tar Roofing Pitch	4.3	2040	13.9	.0023	1730
51 Paraffin/Polyisobutylene	4.7	1700	14.0	.0037	1130
68 Coal Tar Roofing over HF Treatment	5.3	--	1.9	0	-
69 Sulfur over HF Treatment	4.7	--	+2.6	0	2300
70 Modified Paraffin	5.0	2000	8.6	.006	1520
72 Modified Paraffin	2.7	1370	20.2	.013	1080
73a Coal Tar - Hot Specimen	3.8	--	15.6	--	--
b Coal Tar - Cold Specimen	23.6	--	0	0	--

Part E - Hot Melts (cont'd)

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4		
			Wt. Loss (g)	Scaling (in./day)	Flexural Strength Room Cured (psi)
75a Asphalt - Hot Specimen	16.0	--	0.8	0	--
b Asphalt - Cold Specimen	25.0	--	0.2	0	--
76a Cut back Asphalt Hot Specimen	1.8	Tacky - Never set			
b Cut back Asphalt Cold Specimen	3.5	Tacky - Never set			
106 Paraffin Emulsion (Coating only)	1.4	700	17.5	0.0023	685
108 Paraffin Emulsion	2.6	740	14.8	0.0017	650
113 Coal Tar (over nitrile-phenolic tack coat)	16.4	745	0.7	0	835
131 Sulfur impregnated, then coated with Vinyl-Vinylidene Chloride	7.8	--	+2.5	0	2080
132 Sulfur impregnated, then coated with Nitrile-Phenolic Latex	10.8	--	+2.6	0	--
133 Sulfur impregnated, then coated with Rubber Adhesive	13.0	--	0	0	--
134 Sulfur impregnated, then coated with Reclaimed Rubber	13.0	--	0	0	--

Part E - Hot Melts (cont'd)

Specimen #	Resin Absorption (%)	Flexural Strength (psi)	After exposure to 10% H_2SO_4		
			Wt. Loss (g)	Scaling (in./day)	Flexural Strength Room Cured (psi)
135 Coal tar Pitch over Special Primer	16.0	--	0	0	--
136 Asphalt-Gilsonite Product	16.0	--	18.1	0.011	--

APPENDIX B

Detailed Materials' Cost and Impregnation or Coating Costs

DETAILED MATERIALS COST AND IMPREGNATION OR COATING COSTS

Pipe Diameter Class B (in.)	Pipe Density (lb/ft)	Sulfur at a Cost of $0.01/lb: Impregnated Sulfur at 10% (lb)	Cost ($/ft)	Internal Surface Area/ft	Hand Labor Cost at $0.25/ft^2 ($/ft)	Automated Process at 2x Sulfur Cost ($/ft)	Hand Labor Materials & Labor ($/ft)	5% HF Solution at $0.015/lb: HF Req'd for 5% (lb)	Cost ($/ft)	Handling Cost at $0.0005/lb ($/ft)	Total Cost ($/ft)
18	173	17.3	.173	4.72	1.18	0.35	1.35	8.7	.13	.09	0.22
24	276	27.6	.276	6.28	1.57	0.55	1.85	13.8	0.21	0.14	0.35
30	375	37.5	.375	7.85	1.96	.75	2.34	18.8	0.28	0.19	0.47
36	524	52.4	.524	9.42	2.36	1.05	2.88	26.2	0.39	0.26	0.65
48	860	86.0	.860	12.56	3.14	1.72	4.00	43.0	0.65	0.43	1.08
60	1295	129.5	1.295	15.7	3.92	2.59	5.22	64.7	0.97	0.65	1.62

COATINGS

Based on a 15.4g/17.2 in^2 coating

Vinyl Vinylidene Chloride
at $0.18/lb 50% Solution
$0.37/lb Dry basis
180 Vinyl Acetate/Acrylic
at $0.16/lb 55% Solution

Based on a 11.0g/17.2 in^2 coating

Reclaimed Rubber Emulsion at $0.40/lb
of Nitrile-phenolic resin
at $0.40/lb

Dia.	ft^2/ft	Wt/ft^2 (lb/ft^2)	Wt/ft (lb/ft)	Material Cost ($/ft)	Labor Cost at 0.25/ft^2	Total Cost $/ft	Wt/ft^2 (lb/ft^2)	Wt/ft (lb/ft)	Material Cost ($/ft)	Labor Cost at $0.25/ft	Total Cost ($/ft)
18	4.72	.285	1.35	0.24	1.18	1.42	.204	.96	0.38	1.18	1.56
24	6.28	"	1.79	0.32	1.57	1.89	"	1.28	0.51	1.57	2.08
30	7.85	"	2.24	0.40	1.96	2.36	"	1.60	0.64	1.96	2.60
36	9.42	"	2.68	0.48	2.36	2.84	"	1.92	0.77	2.36	3.13
48	12.56	"	3.58	0.65	3.14	3.79	"	2.56	1.02	3.14	4.16
60	15.7	"	4.48	0.81	3.92	4.73	"	3.20	1.28	3.92	5.20

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
	08G	

5 Organization

Southwest Research Institute
San Antonio, Texas

6 Title

IMPREGNATION OF CONCRETE PIPE,

10 Author(s)

Ludwig, Allen C.
Dale, John M.

16 Project Designation

Contract #14-12-835
Program 11024 EQE

21 Note

22 Citation

23 Descriptors (Starred First)

Concrete,* Concrete pipes,* Corrosion,* Corrosion control,* Protective coatings,* Sewers,* Sulfur,* Hydrogen sulfide, Resins

25 Identifiers (Starred First)

Impregnation,* Hydrofluoric acid,* Acid resistance,* Bacterial action,* Sulfate resistance*

27 Abstract

Methods to increase the corrosion resistance, increase the strength, and reduce the permeability of concrete used in sewer line applications by impregnating the concrete pipe with relatively low cost resins such as asphalt, coal tars, linseed oil, sulfur, urea-formaldehyde, and others were investigated.

The materials, techniques of application, test results and economics are presented. A large number of candidate impregnation materials were obtained and screened both in the laboratory and in limited field tests. Dilute hydrofluoric acid, sulfur and modified sulfur were found to impart the best corrosion resistance by impregnation. Other materials including vinyl-vinylidene chloride, vinyl acetate-acrylic, nitrile rubber latex, nitrile phenolic rubber, an emulsified reclaimed rubber and a rubber base adhesive, although failing to impregnate the concrete, formed surface coatings having exceptional corrosion resistance.

This report was submitted in fulfillment of Program No. 11024 EQE, Contract No. 14-12-835 under the sponsorship of the Water Quality Office, Environmental Protection Agency. (Ludwig-Southwest Research Institute)

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